Resilience Analytics and Economic Modeling

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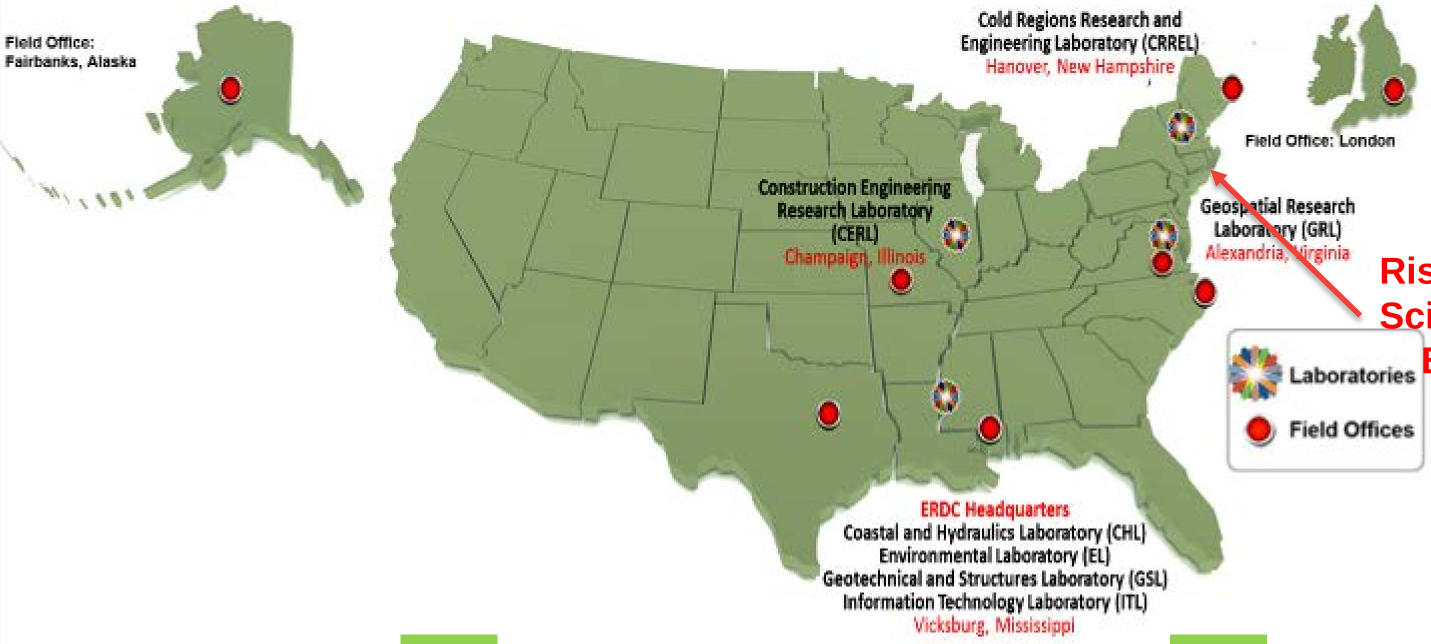
Collaborators:
Ben Trump and Jeff Cegan (USACE)
Melissa Surette (FEMA)
Susan Cibulsky (HHS/ASPR)

About Army Engineer R&D Center



7 Laboratories

Coastal and Hydraulics Laboratory (CHL)
Cold Regions Research and Engineering Laboratory (CRREL)
Construction Engineering Research Laboratory (CERL)
Environmental Laboratory (EL)
Geospatial Research Laboratory (GRL
Geotechnical and Structures Laboratory (GSL)
Information Technology Laboratory (ITL)

Annual Research Program Exceeding
$1.3 Billion

People

2100 Strong
61% E&S
71% of E&S with
Advanced Degrees
29% of E&S with PhD

Core Competencies

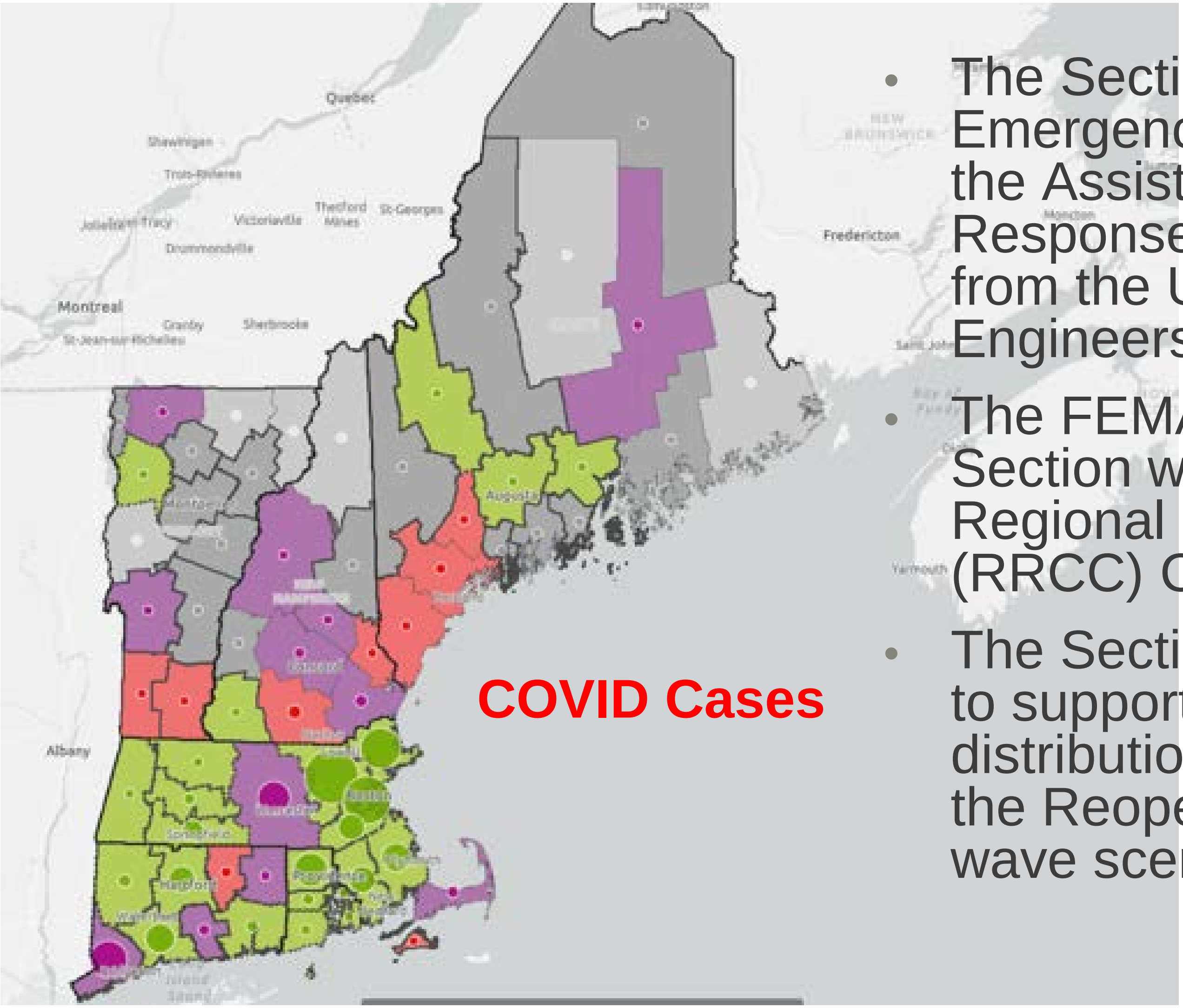
- Blast and Weapons Effects on Structures and Geo-Materials
- 3-D Mapping and Characterization
- Cold Regions Science and Engineering
- Civil and Military Engineering
- Computational Prototyping of Military Platforms
- Coastal, River, and Environmental Engineering
- Military Installations and Infrastructure

Partners

All DoD Services
Army, Navy, Air Force, NASA, DHS, FEMA, DIA, NGA
Academia
68 EPAs with top engineering schools
Industry
172 CRADAs
International
14 international agreements with 7 countries

US Army Corps of Engineers
U.S. ARMY

FEMA/ASPR Reg. 1 Data Analytics Section



- The Section is co-led by the Federal Emergency Management Agency (FEMA) and the Assistant Secretary for Preparedness and Response (ASPR), and includes personnel from the United States Army Corps of Engineers (UASCE)
- The FEMA/ASPR Region 1 Data Analytics Section was established to support the Regional Response Coordination Center (RRCC) COVID-19 response efforts
- The Section provides modeling and analysis to support and inform decisionmakers on the distribution of resources, fatality management, the Reopening of America efforts, and second wave scenarios

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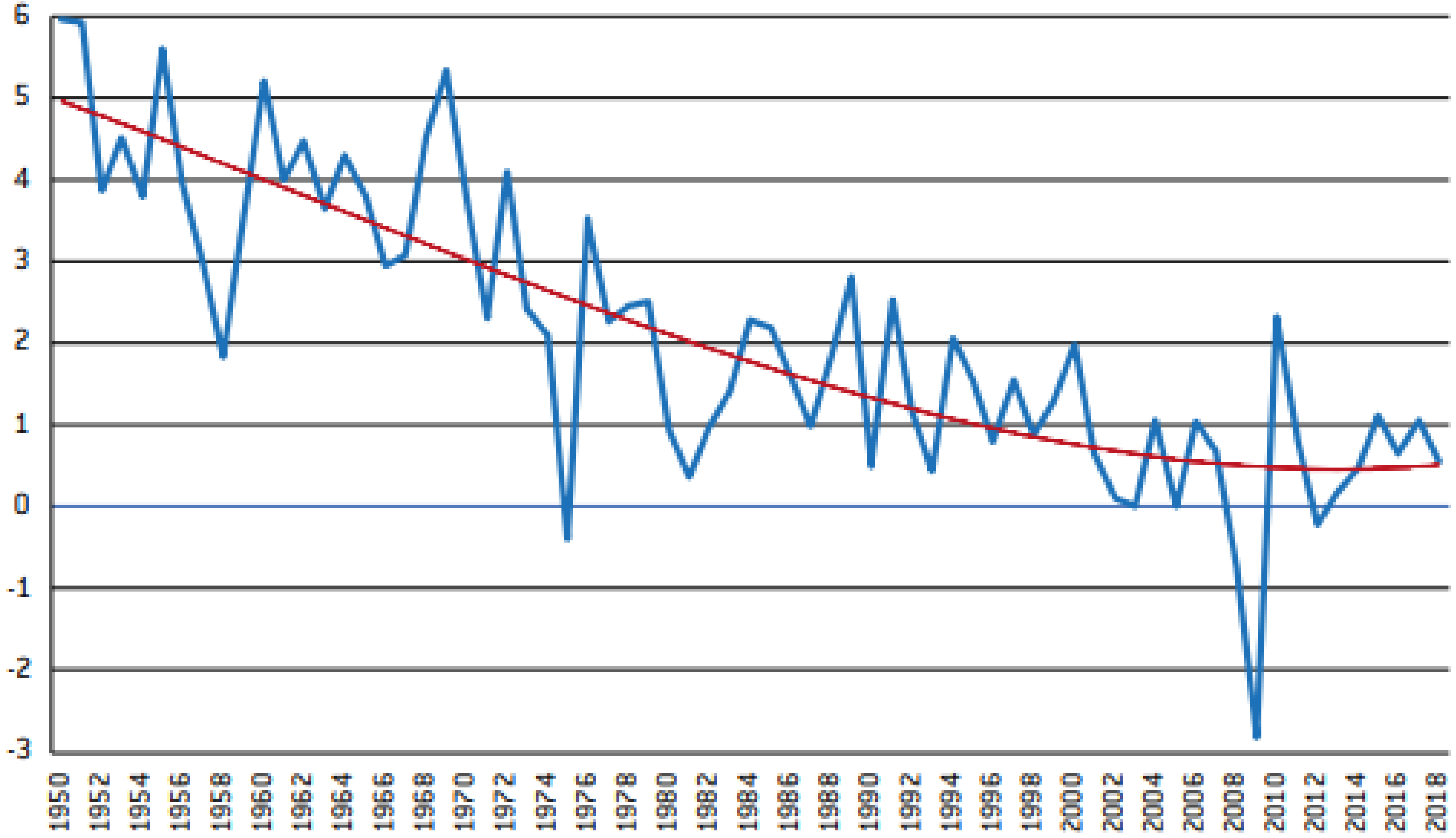
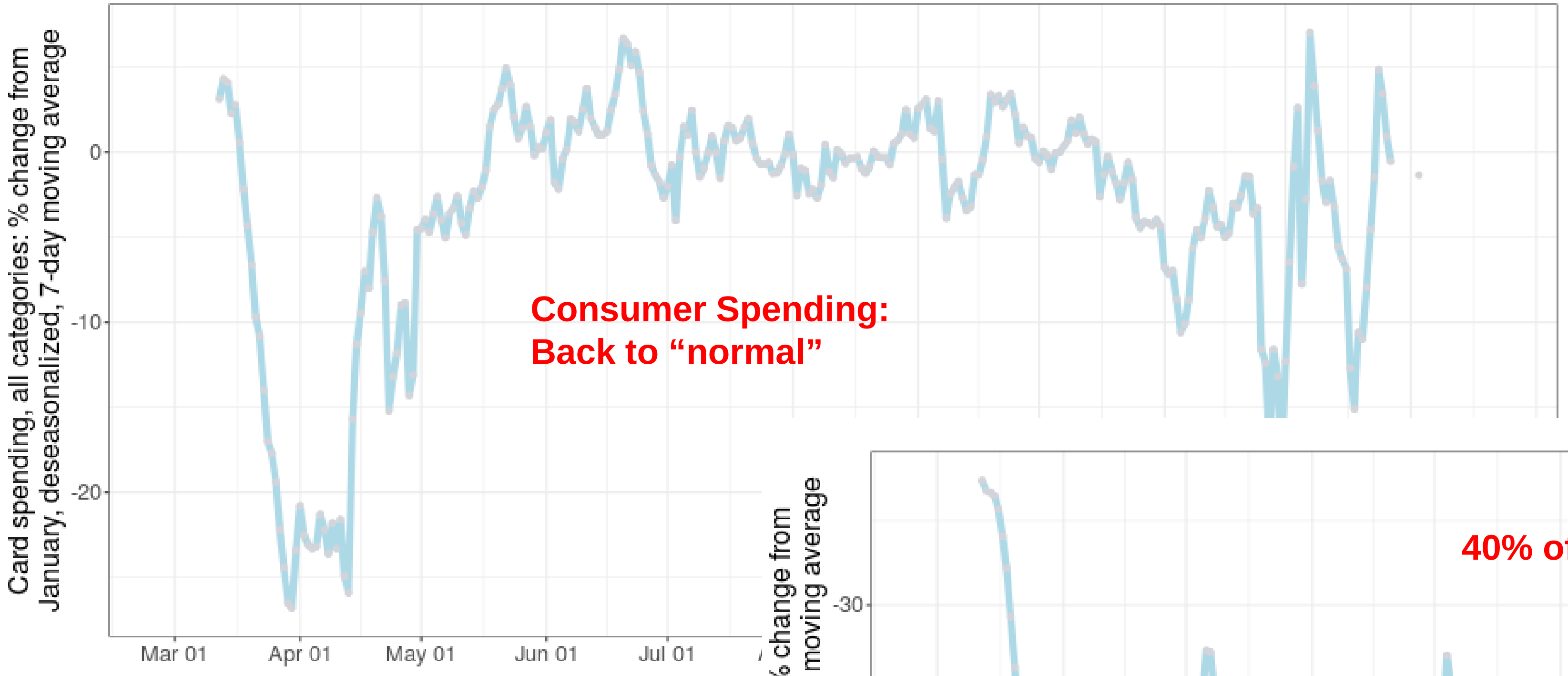
Productivity Paradox: Euro Area total factor productivity



Source: Bergeaud *et al* (2016), database updated in 2019 available at http://www.longtermproductivity.com/.

Post-COVID Productivity indicators for the state of Maine



Outline

Team: USACE/FEMA/HHS – science of resilience, framing the problem, application to COVID in FEMA Region 1 and worldwide.

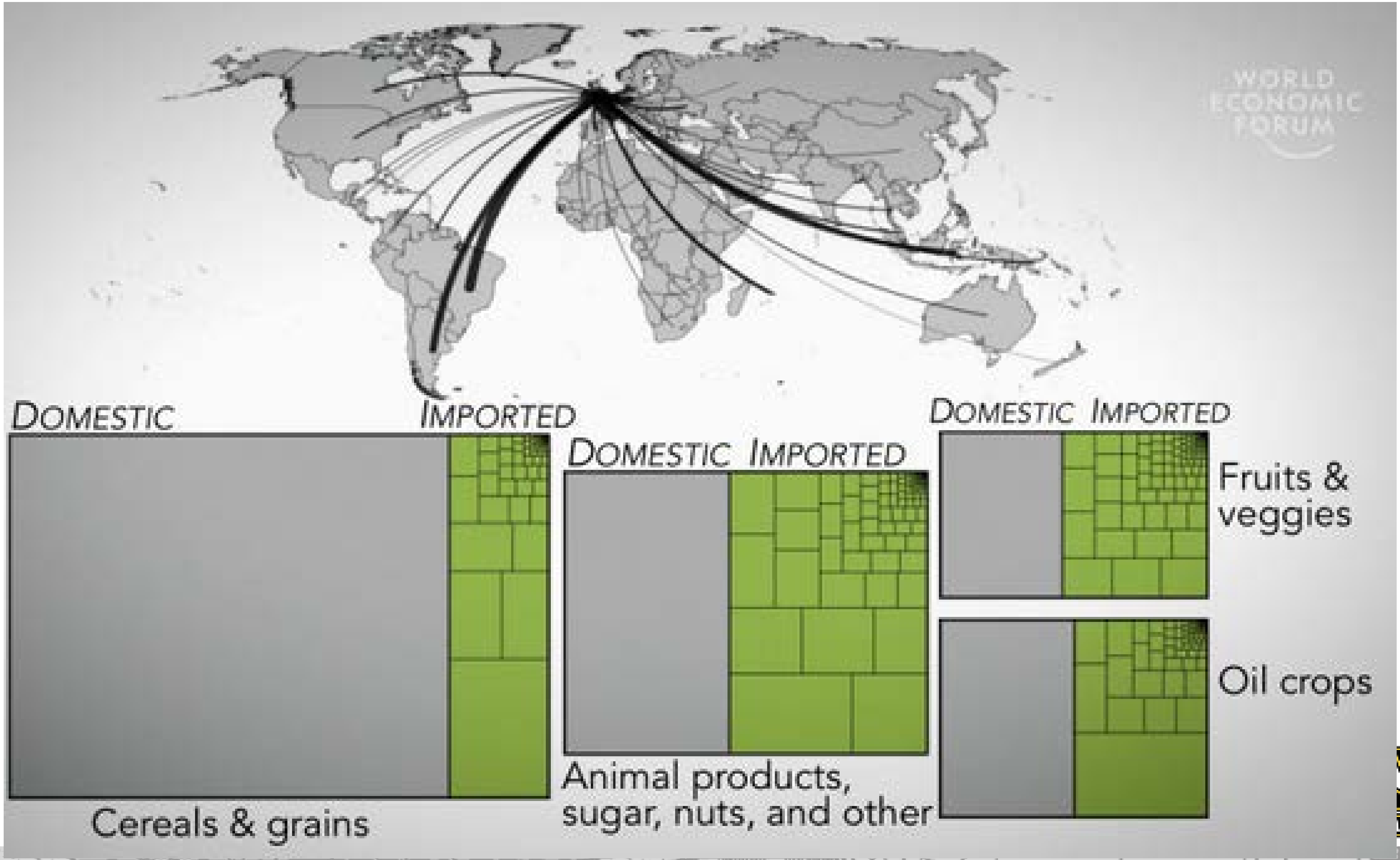
Complex Systems and Resilience: efficiency vs. resilience

Science of Resilience: Historical perspectives (Venice), resilience quantification using metrics-based (Resilience Matrix) and model-based (Network Science) approaches.

Application Example – Financial Implication of Lack of Resilience

Conclusion: Resilience based approaches and economic analyses need to be integrated to assure both efficiency and resilience in operation of complex systems that communities rely on

Economic Systems are Global

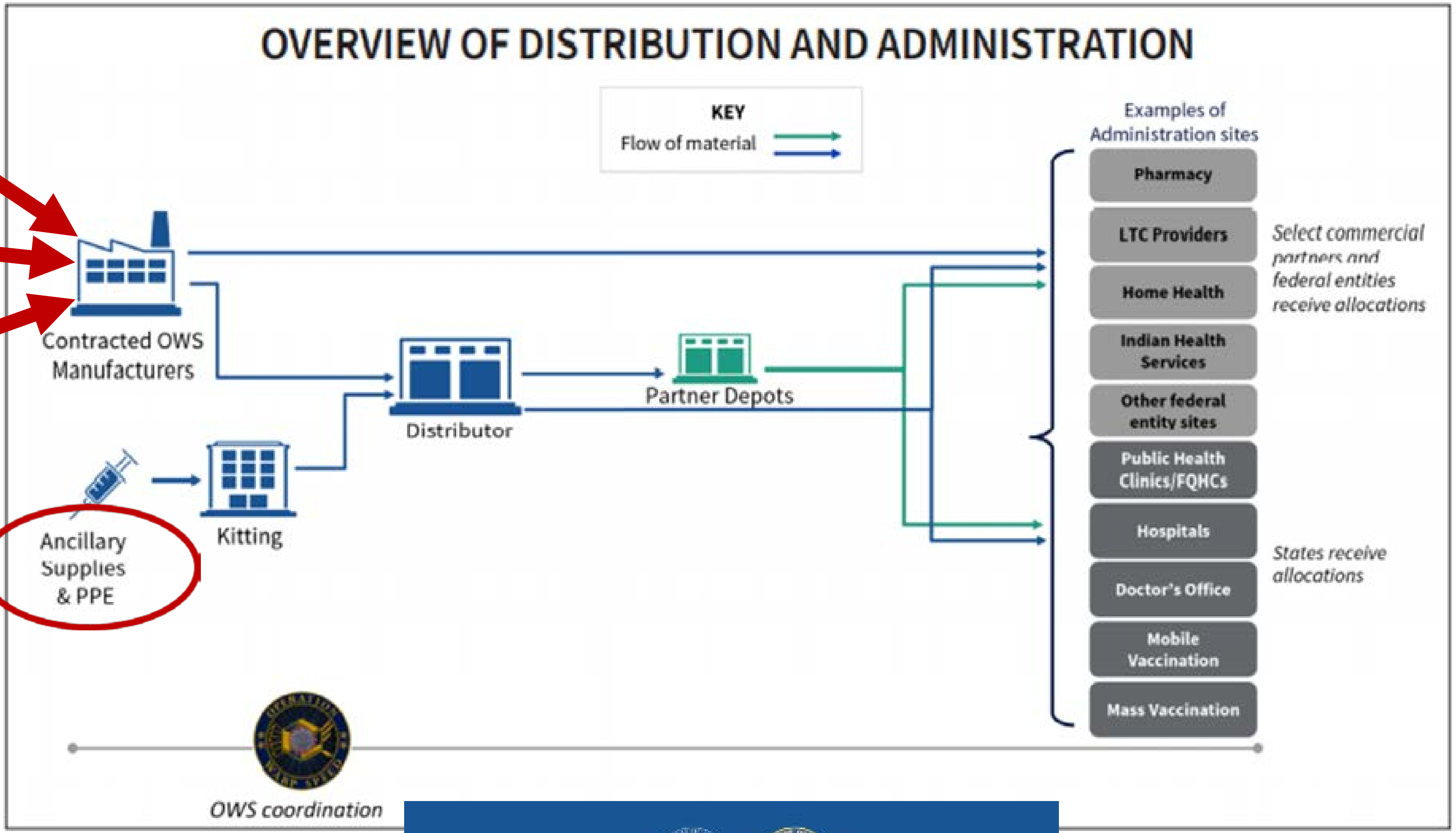


vaccine production Dependent on many components and connections that may be failing

Quality chemical agents

Quality biological agents

Bioreactors, microcarriers, serums, etc.



Are these likely points of failure and if so, how will vaccine manufacture persevere to meet vaccination targets?

From the Factory to the Frontlines

The Operation Warp Speed Strategy for Distributing a COVID-19 Vaccine

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How to Enhance supply chain productivity and efficiency and be resilient?

MANAGE SUPPLY RISK

1. Conduct thorough supply and supplier risk assessments
2. Increase supply redundancy through multi-source awards
3. Increase safety stock of critical materials
4. Regionalize the supply of critical materials

ENHANCE END-TO-END VISIBILITY THROUGH DIGITIZATION

5. Develop forward-sensing abilities to improve demand prediction
6. Leverage analytics and establish control towers to gain greater end-to-end visibility
7. Increase data sharing and transparency with customers and partners
8. Explore opportunities to harvest cutting edge technologies

BOOST SUPPLY CHAIN AGILITY

9. Stress-test business continuity plans to prepare for the next crisis
10. Build redundancy into your operations
11. Empower teams through increased workforce flexibility

USE A PATIENT-CENTRIC APPROACH

12. Build digital capabilities to support changing consumer behaviors
13. Implement risk sensing solutions to gain real time understanding of consumer needs and pain points

STRENGTHEN PUBLIC-PRIVATE PARTNERSHIPS

14. Identify collaboration opportunities with federal, state and local governments
15. Engage with the public sector to solve chronic shortages o critical drug
16. Develop joi plans to dis COVID-19 vaccines sa and effectiv

Even small changes to build resilience have a cost, so organizational leaders should make decisions following detailed cost/benefit analysis. Determining the right level of investment requires understanding how vulnerable the organization is and identifying where opportunities for improvement exist.

nature

CORRESPONDENCE · 08 DECEMBER 2020

Combine resilience and efficiency in post-COVID societies

Benjamin D. Trump, Igor Linkov & William Hynes

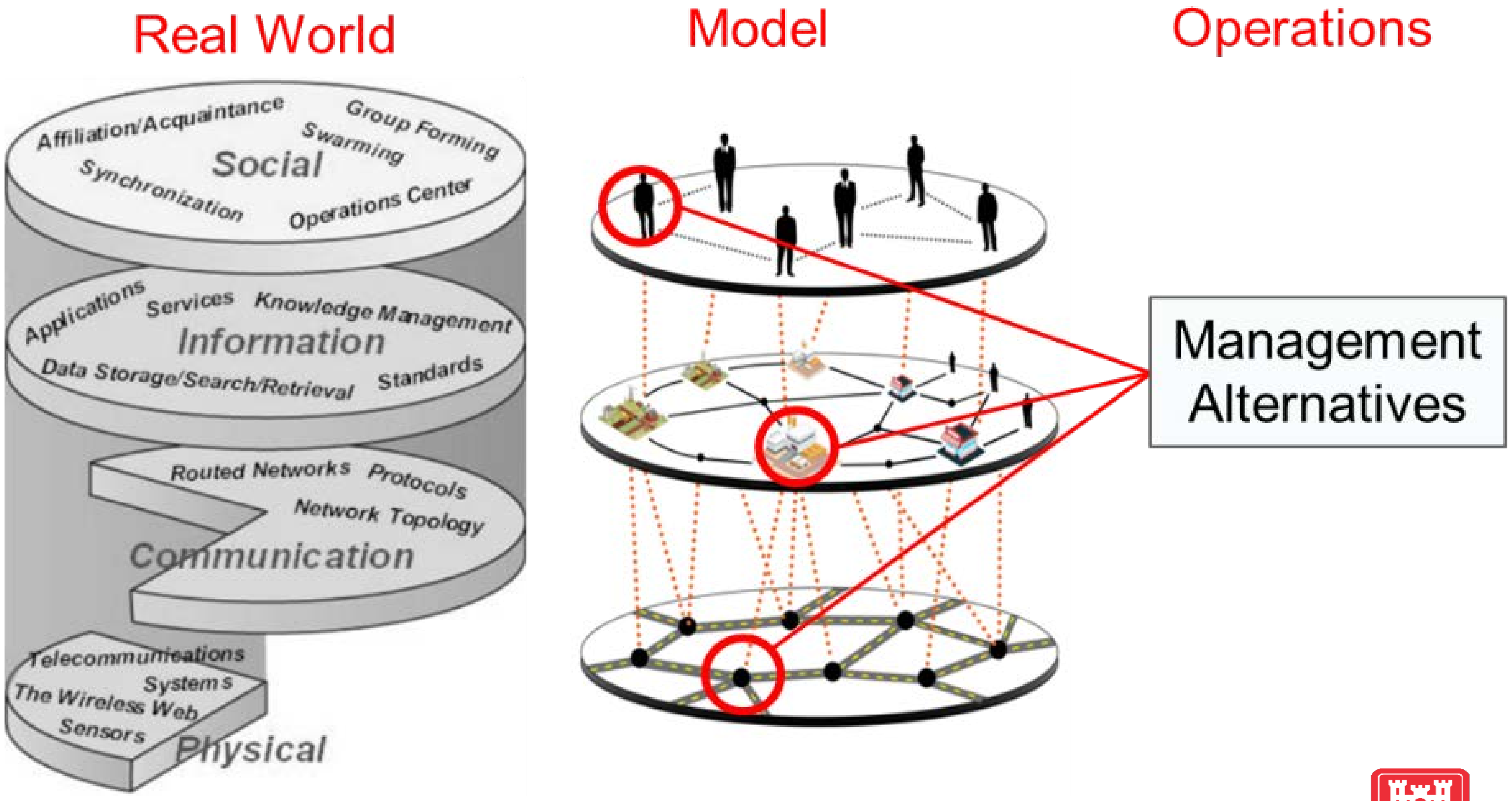
ions/hda-role-of-distributors-in-the-us-health-care-industry.ashx

Deloitte.

HDA RESEARCH FOUNDATION

The First 90 Days:
US Biopharmaceutical Finished Goods Supply Chain Response to COVID-19

Vision for system modeling



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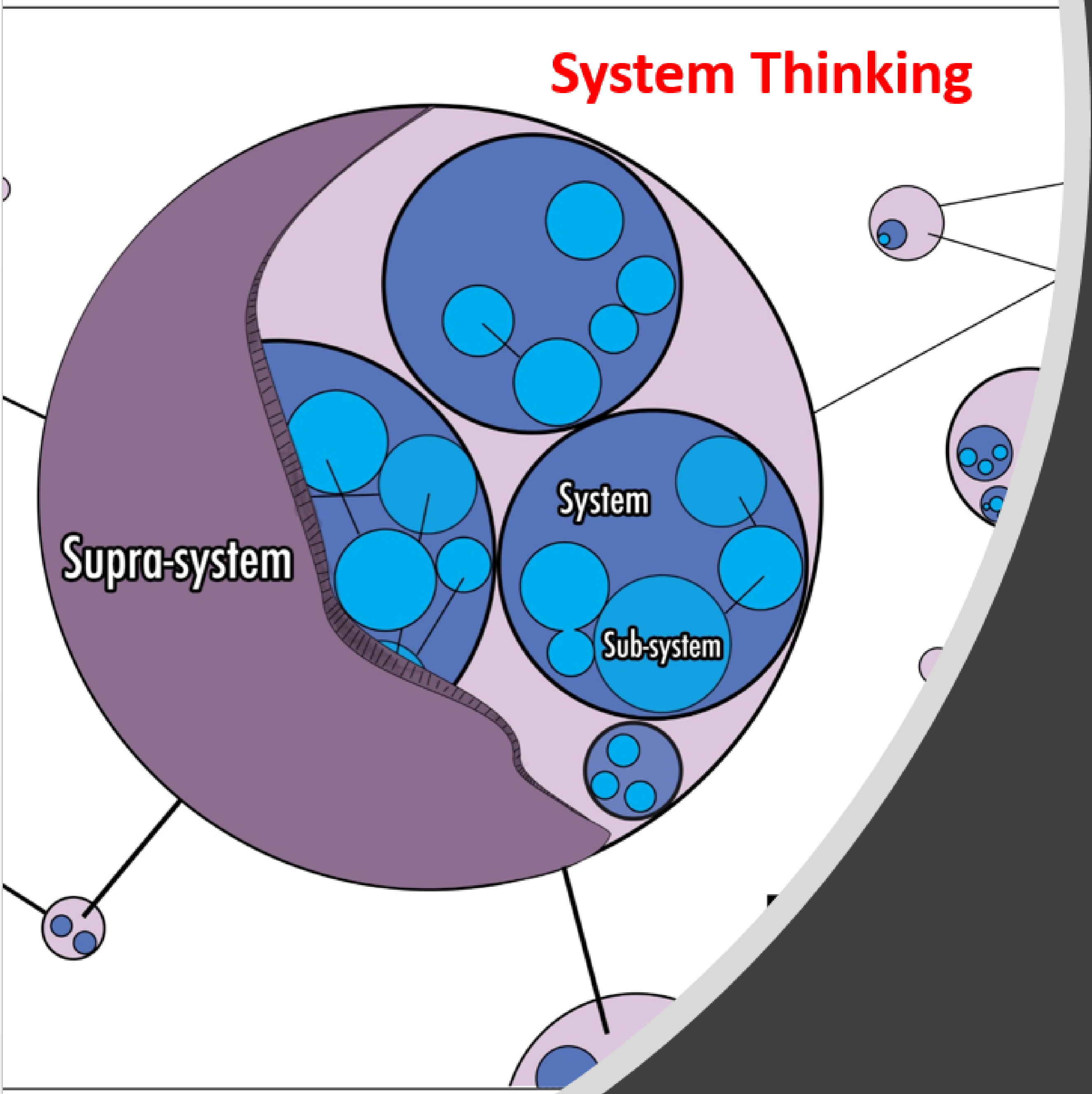
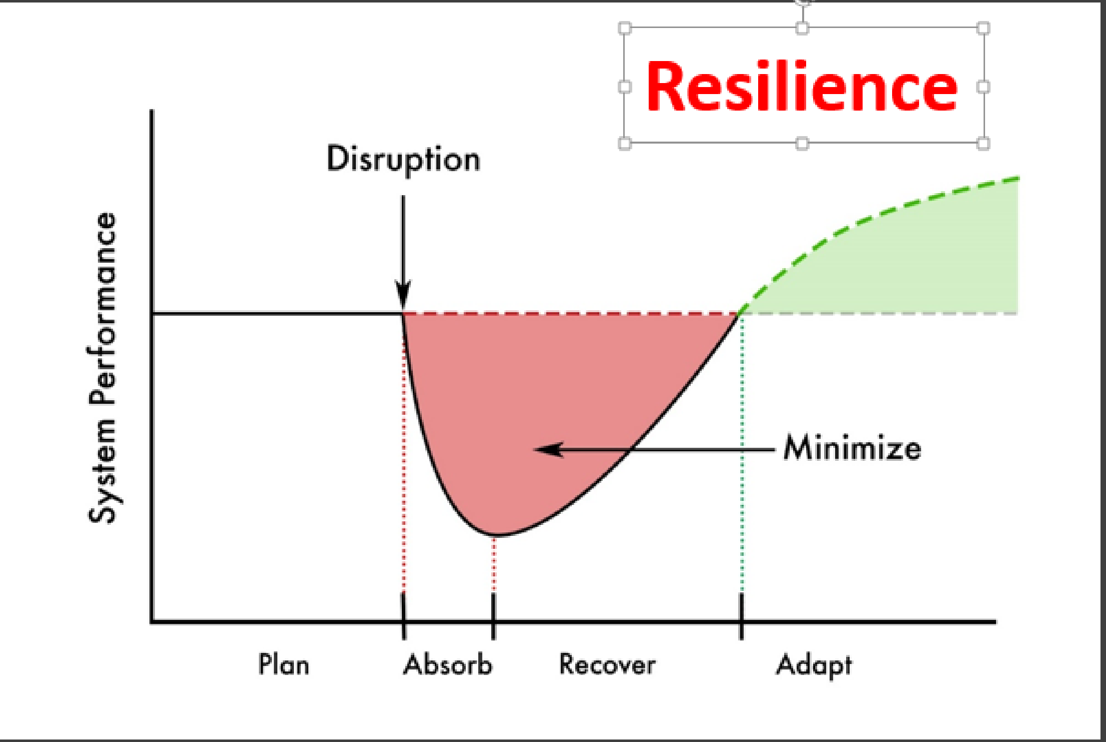
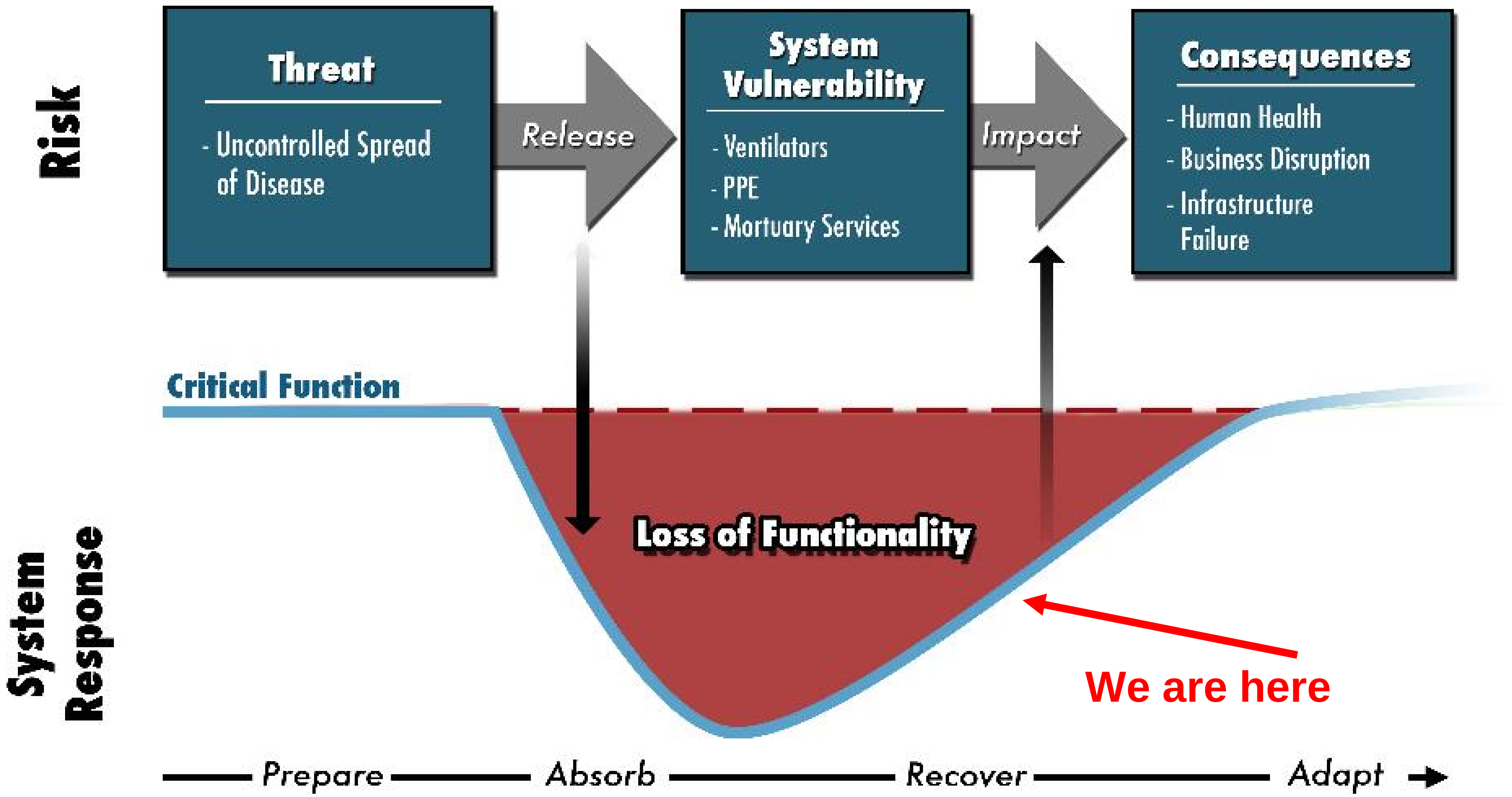


What Makes Complex Systems (Communities) Susceptible to Threat?



After Linkov and Trump, 2019

Moving Towards Resilience



Trump, B., et al (2020). Biosecurity Demands Resilience. *Environmental Science & Technology*, **54,** 4706−4708

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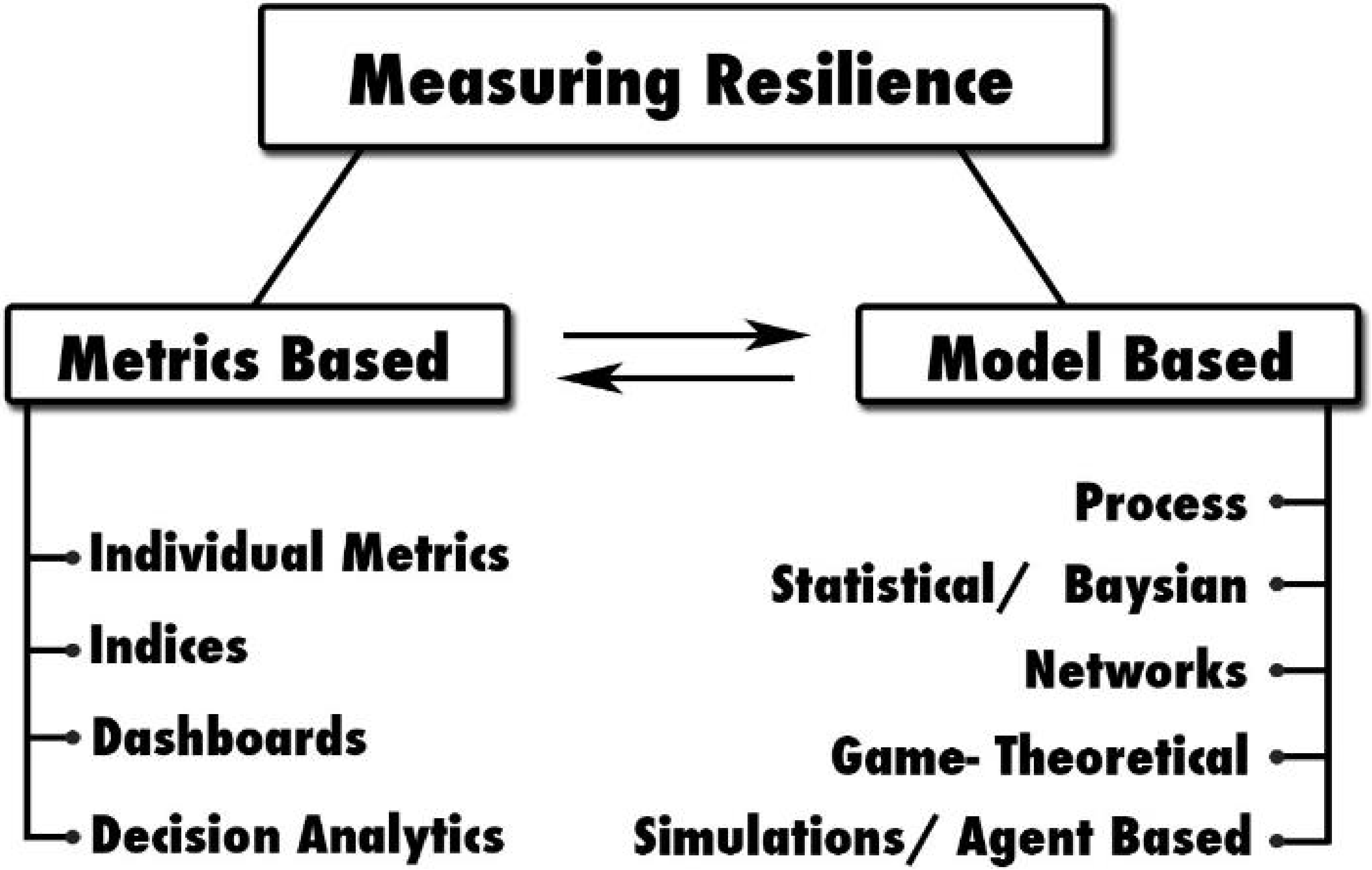
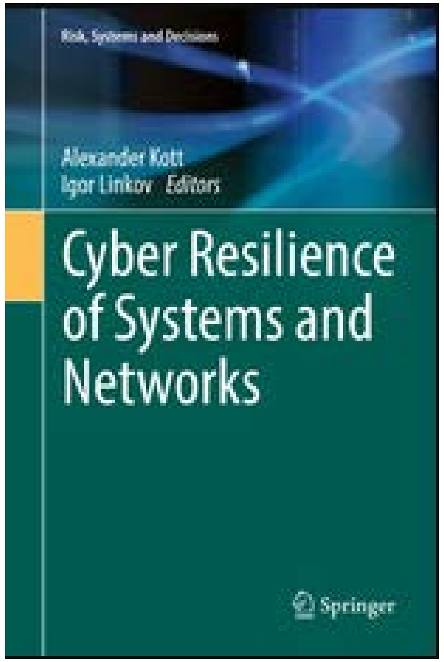
Measuring Resilience in Different Systems



After



After Linkov and Kott, 2019

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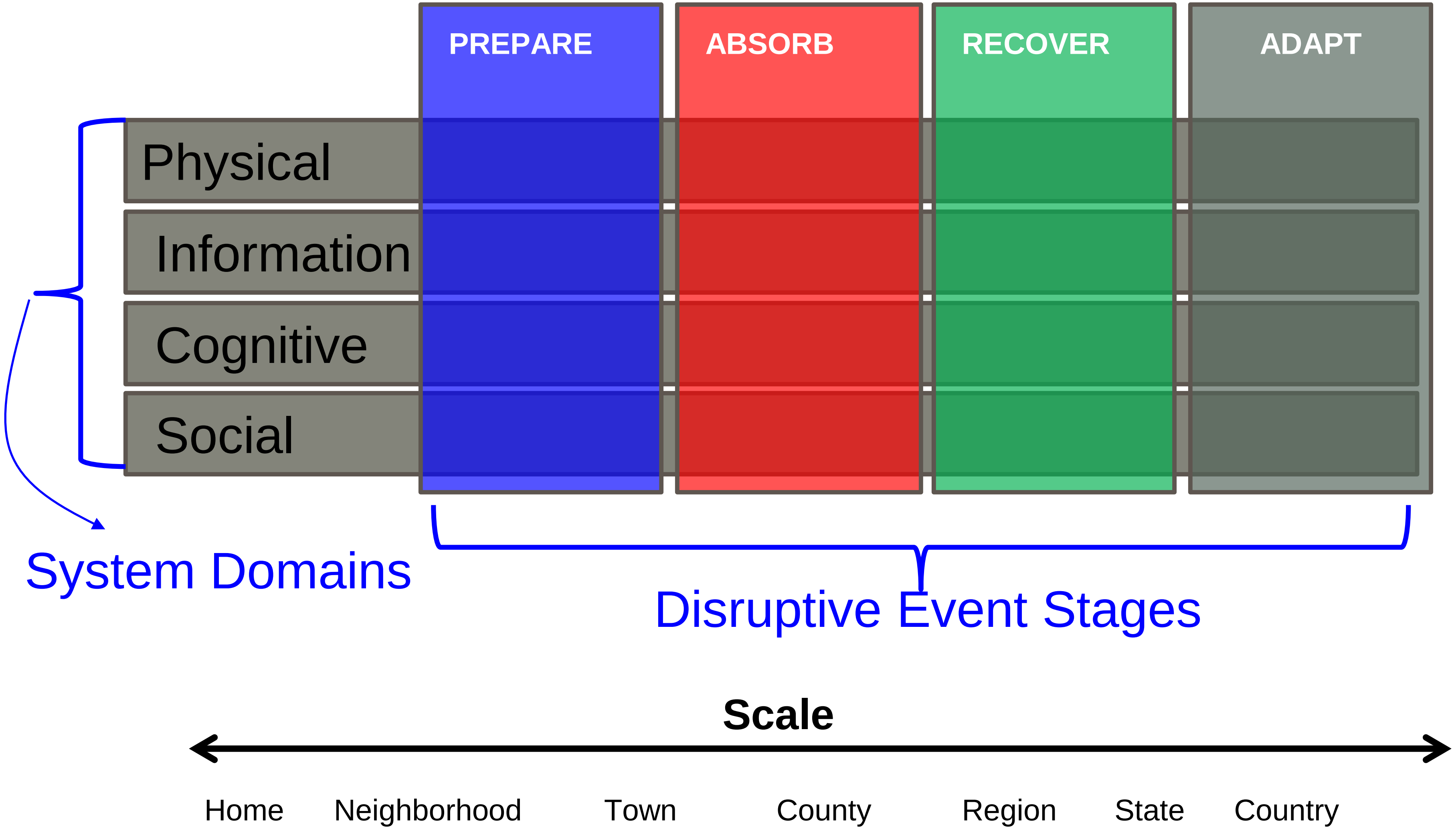
Resilience Matrix



After Linkov et al. (2013)

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Assessment using Decision Maker Values

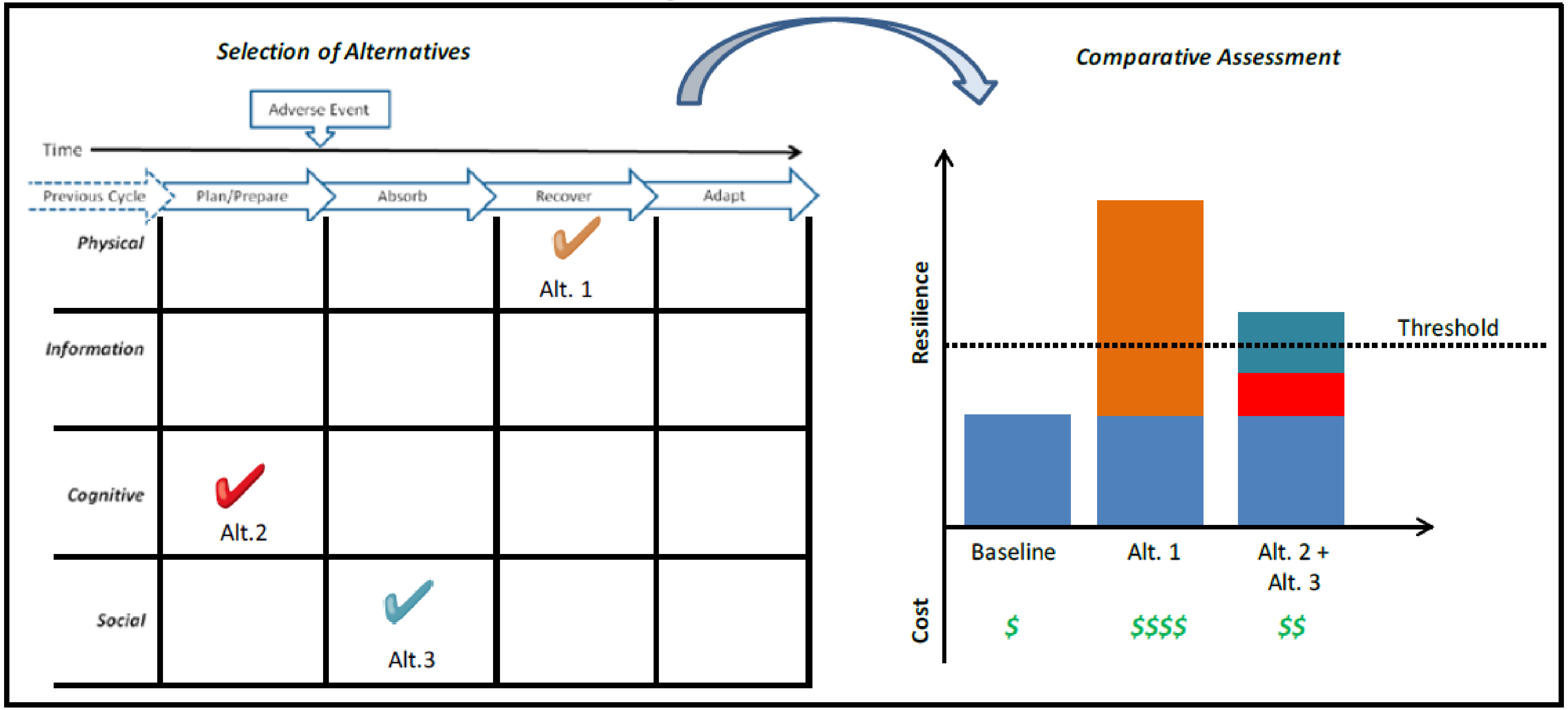

Figure 5: Comparative Assessment of Resilience-Enhancing Alternatives

Use developed resilience metrics to comparatively assess the costs and benefits of different courses of action

After Fox-Lent et al. (2015)

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RESILINC – example of metric-based approach

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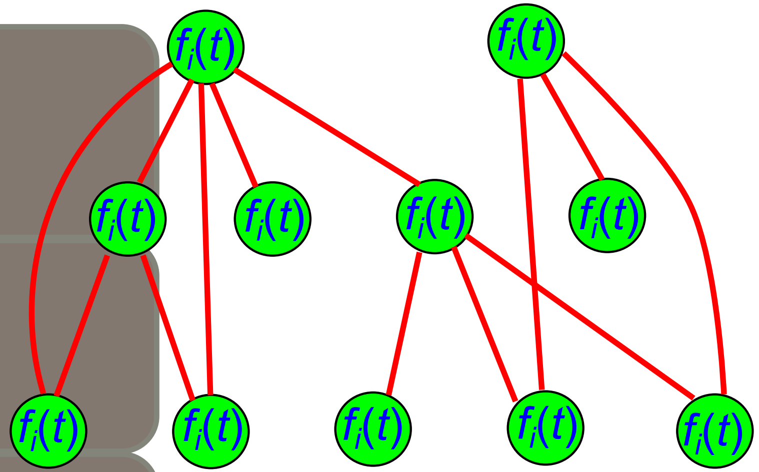
Network-based Resilience Theory?

System's *critical functionality* (K)

Network topology: *nodes* ($\mathcal{N}$) and *links* ($\mathcal{L}$)

Network *adaptive algorithms* ($\mathcal{C}$) defining how nodes' (links') properties and parameters change with time

A *set of possible damages* stakeholders want the network to be resilient against ($\boldsymbol{E}$)



After Ganin et al., 2016

$$R = f(\mathcal{N}, \mathcal{L}, \mathcal{C}, \boldsymbol{E})$$

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Poor Efficiency:

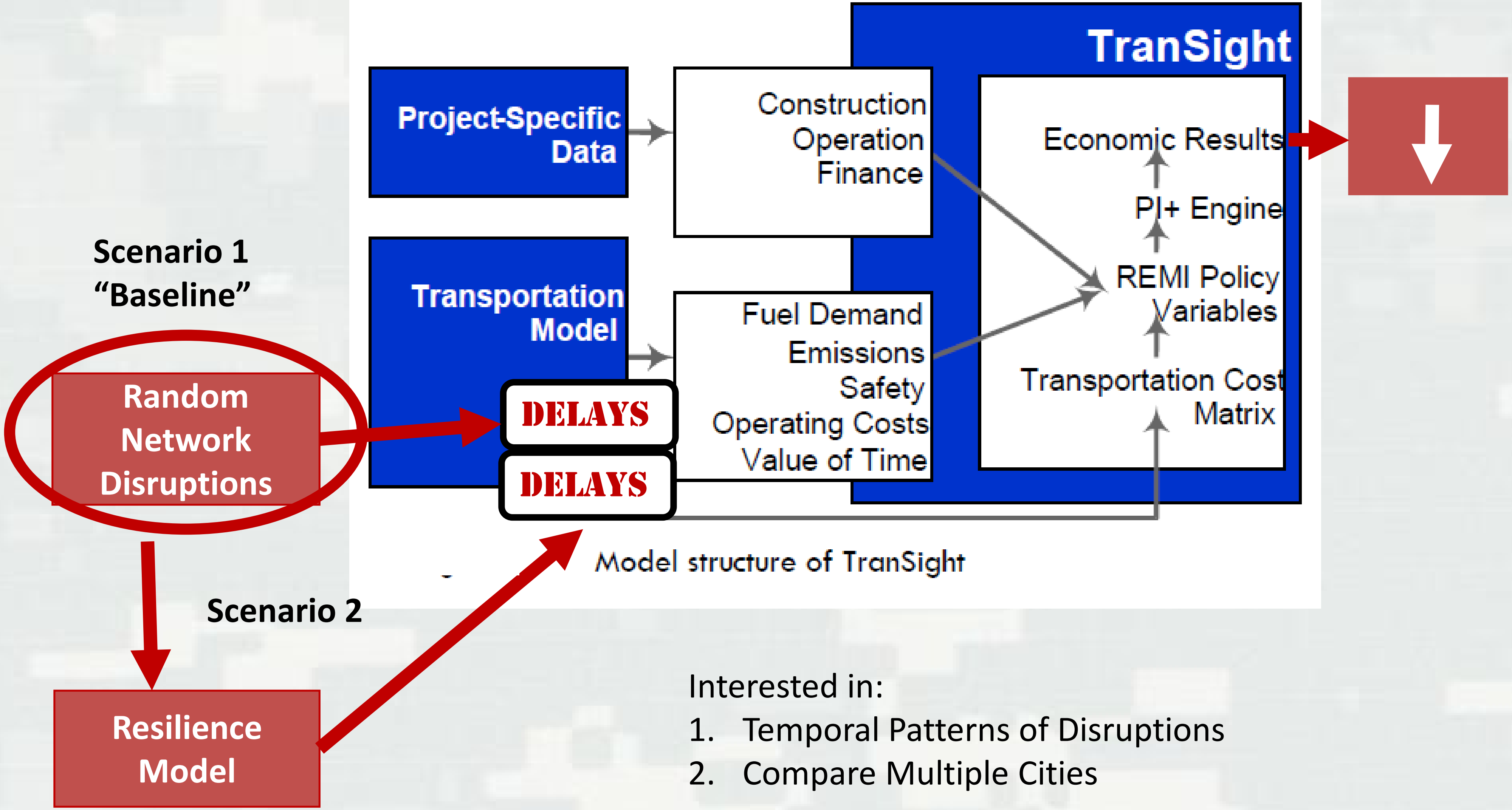
System cannot not accommodate a large volume of commuters driving at the same time.

Traffic congestions are predictable and are typically of moderate level.

Lack of Resilience:

System cannot recover from adverse events
(car accidents, natural disasters)

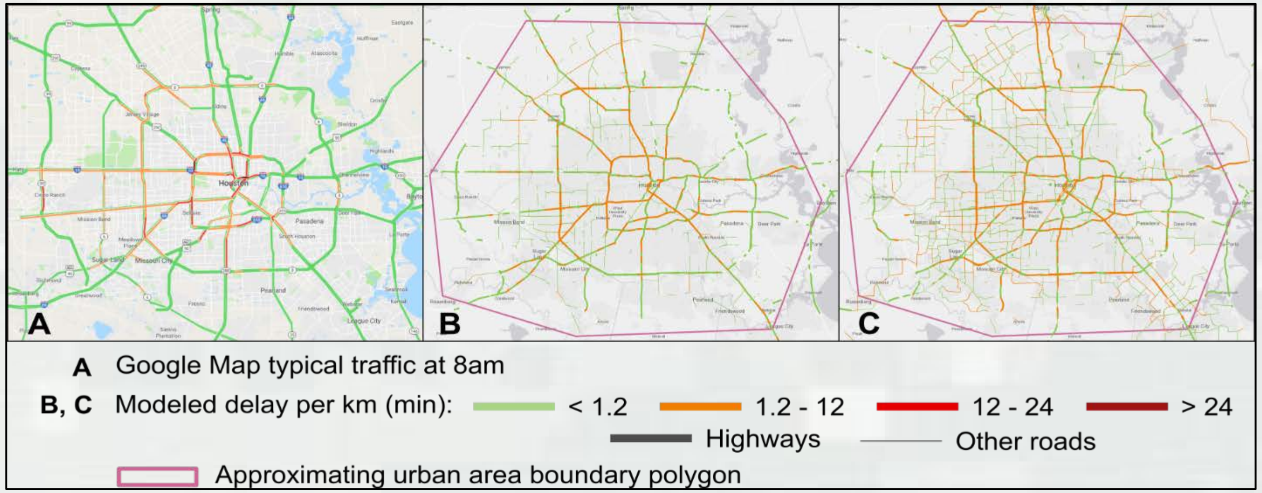
Traffic disruptions are not predictable and of variable scale.



Model structure of TranSight

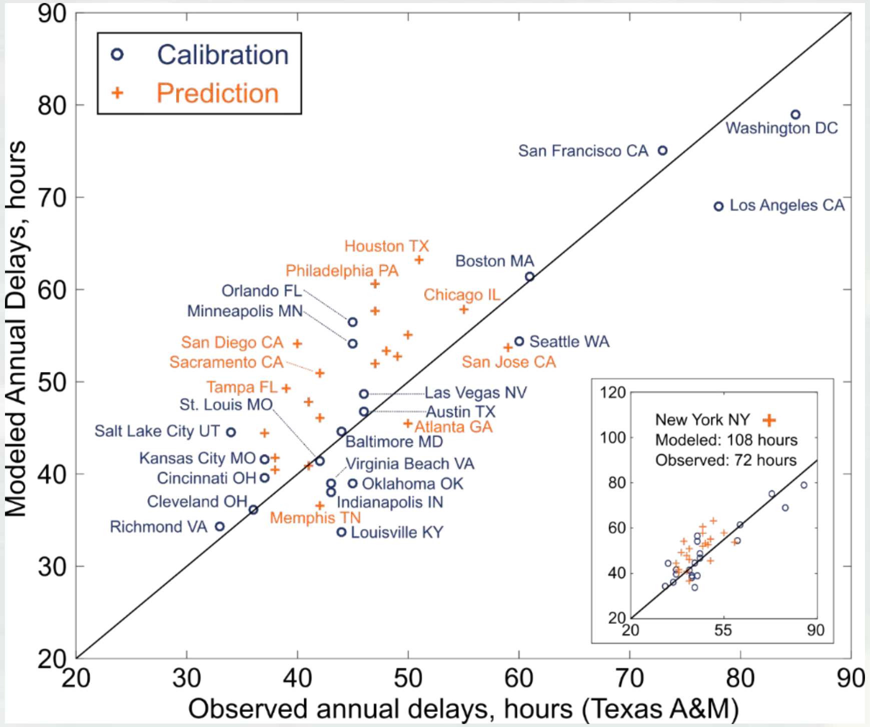
Interested in:
1. Temporal Patterns of Disruptions
2. Compare Multiple Cities

Transportation Network Model:



1) Build networks comprise of road links and intersection nodes
2) Assign travelers and routes
3) Calculate free flow travel times and actual travel times
4) Calculate normal delay
5) Calibrate model to data

$$\langle \Delta T \rangle = \frac{1}{N_c} \sum_{\{ij\} \in \text{all roads}} L_{ij} \ell_{ij} \left(\frac{1}{v_{ij}} - \frac{1}{v_{ij}^0} \right)$$



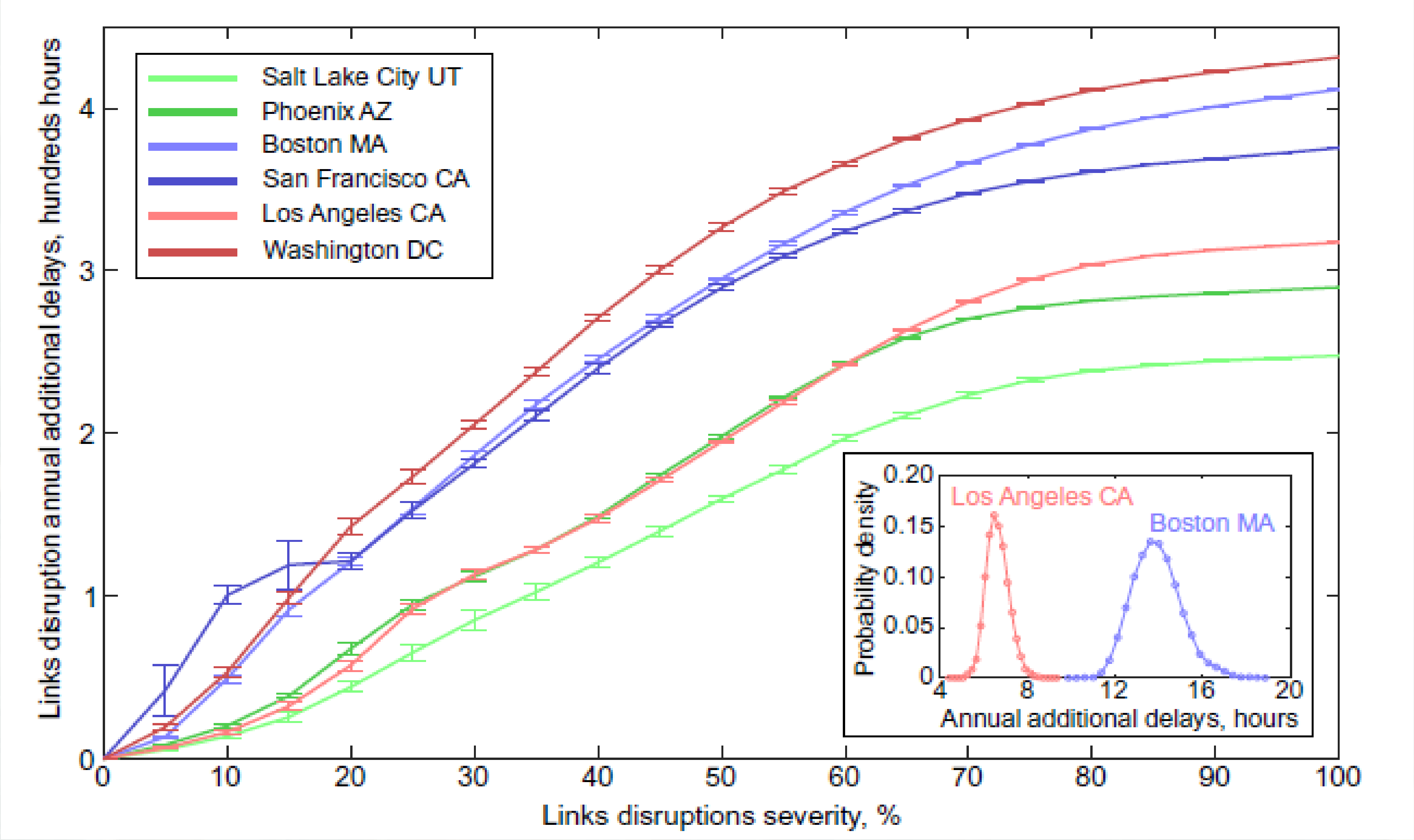
Transportation Networks in 40 Cities

SCIENCE ADVANCES | RESEARCH ARTICLE

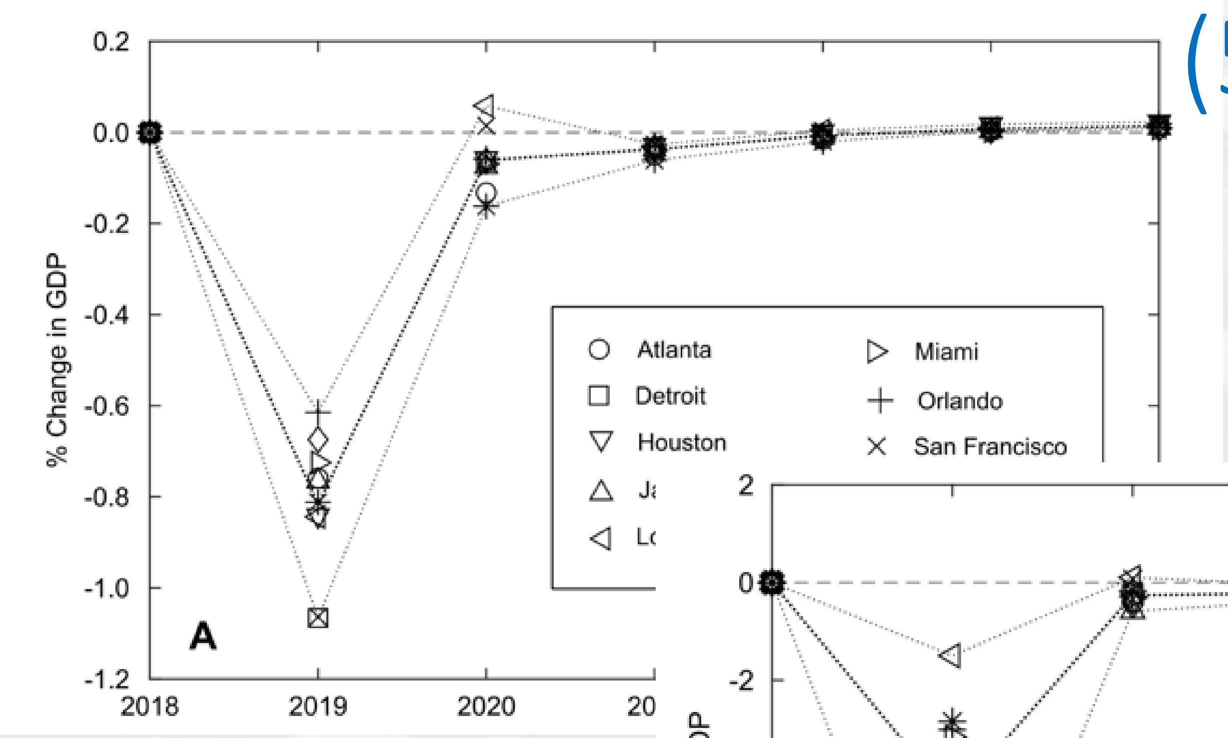
NETWORK SCIENCE

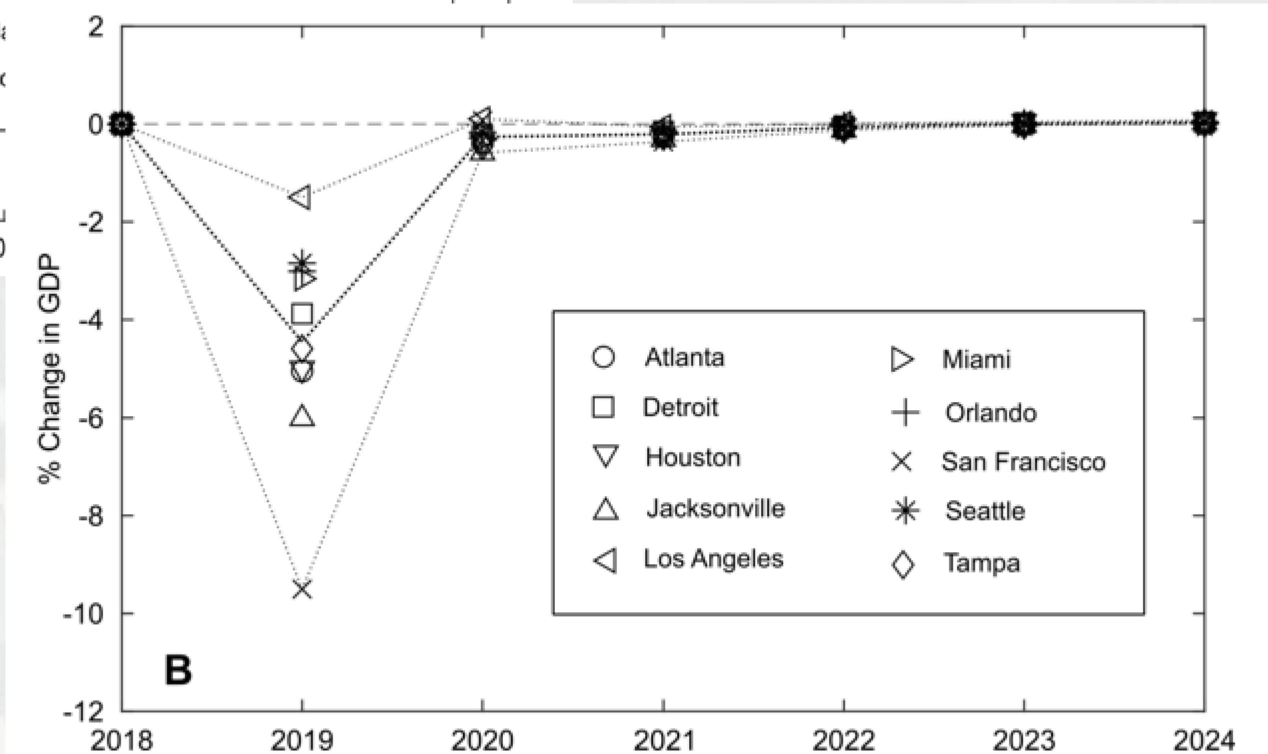
Resilience and efficiency in transportation networks

Alexander A. Ganin,[1,2] Maksim Kitsak,[3] Dayton Marchese,[2] Jeffrey M. Keisler,[4] Thomas Seager,[5] Igor Linkov[2]*

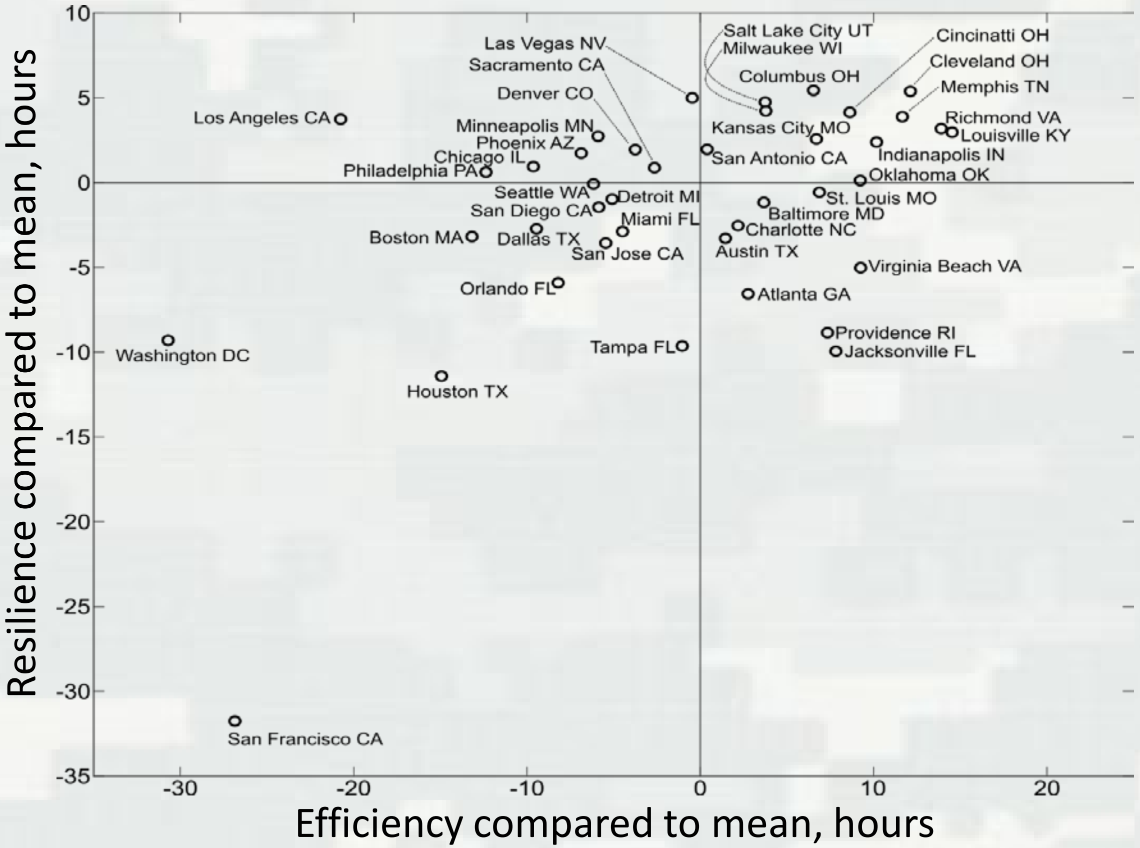


Temporal Pattern of Recovery) (5% disruption)





Resilience vs Efficiency at 5% disruption



SCIENCE ADVANCES | RESEARCH ARTICLE

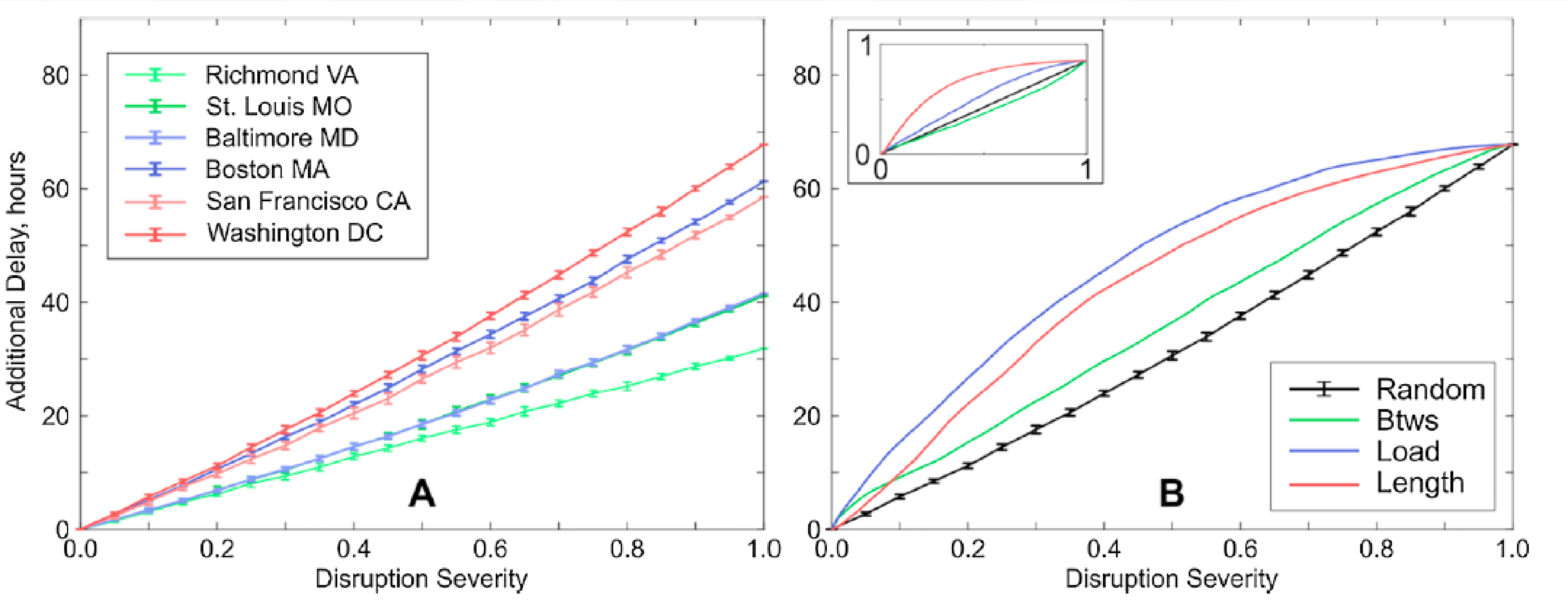
NETWORK SCIENCE

2017

Resilience and efficiency in transportation networks

Alexander A. Ganin,[1,2] Maksim Kitsak,[3] Dayton Marchese,[2] Jeffrey M. Keisler,[4] Thomas Seager,[5] Igor Linkov[2]*

Impact of Cyber Attack on Transportation Network



Contents lists available at ScienceDirect

2019

Transportation Research Part C

journal homepage: www.elsevier.com/locate/trc

ELSEVIER

Resilience in Intelligent Transportation Systems (ITS)

Alexander A. Ganin[a,b], Avi C. Mersky[a], Andrew S. Jin[c], Maksim Kitsak[d], Jeffrey M. Keisler[e], Igor Linkov[a,*]

Increase in Transportation Costs

		Fraction of Affected Roadways (Network Links), ρ				
		1%	2%	3%	4%	5%
Transportation Cost Increase, $c(\rho)$	**Atlanta**	4%	10%	16%	23%	**33%**
	Detroit	3%	6%	9%	14%	19%
	Houston	5%	11%	16%	24%	**32%**
	Jacksonville	7%	13%	22%	**33%**	**44%**
	Los Angeles	1%	3%	5%	7%	9%
	Miami	4%	9%	13%	18%	23%
	Orlando	4%	9%	14%	20%	**26%**
	San Francisco	9%	20%	**34%**	**43%**	**51%**
	Seattle	3%	6%	9%	13%	17%
	Tampa	6%	12%	20%	**26%**	**37%**

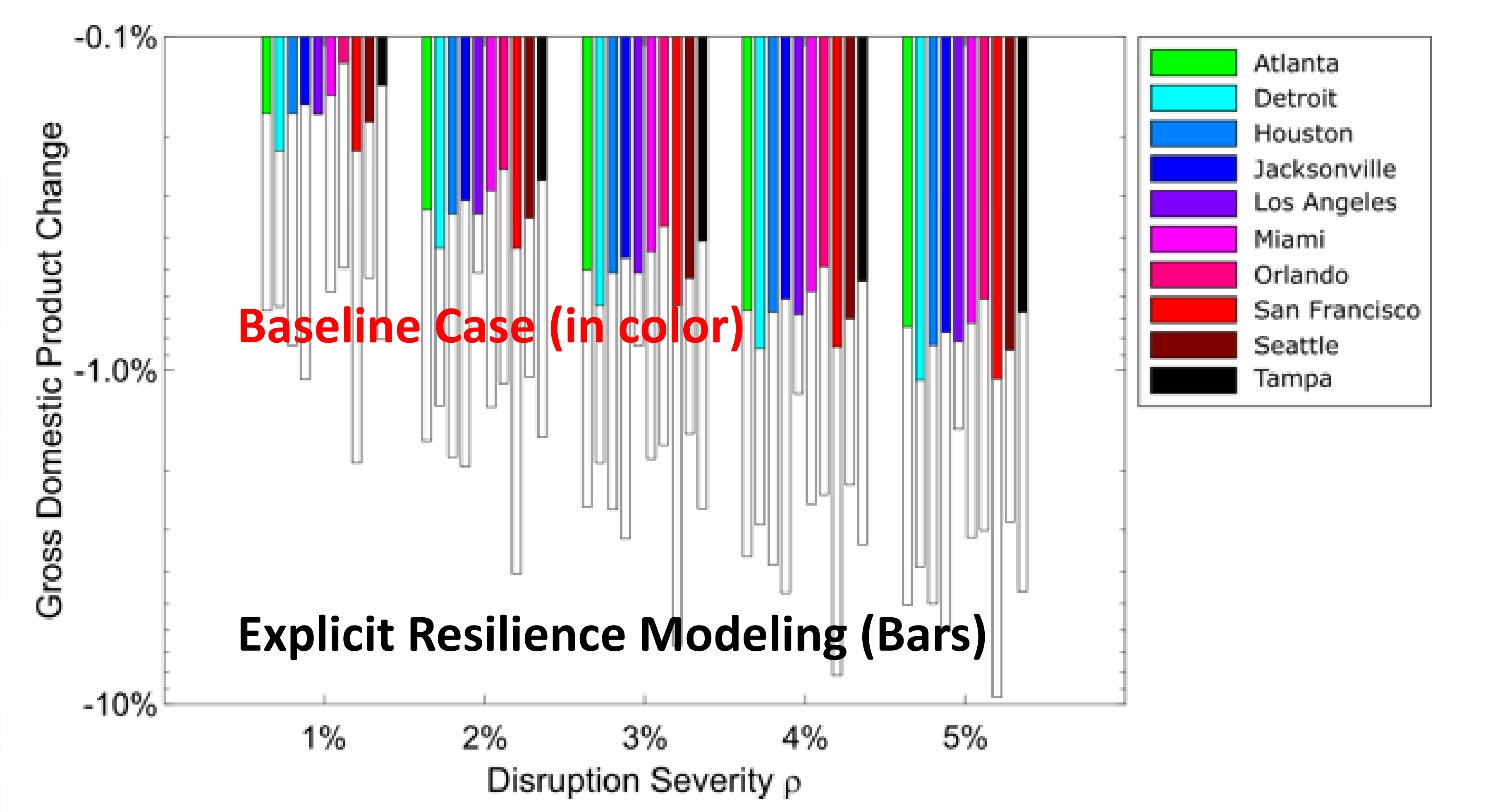
Contents lists available at ScienceDirect

Transportation Research Part D

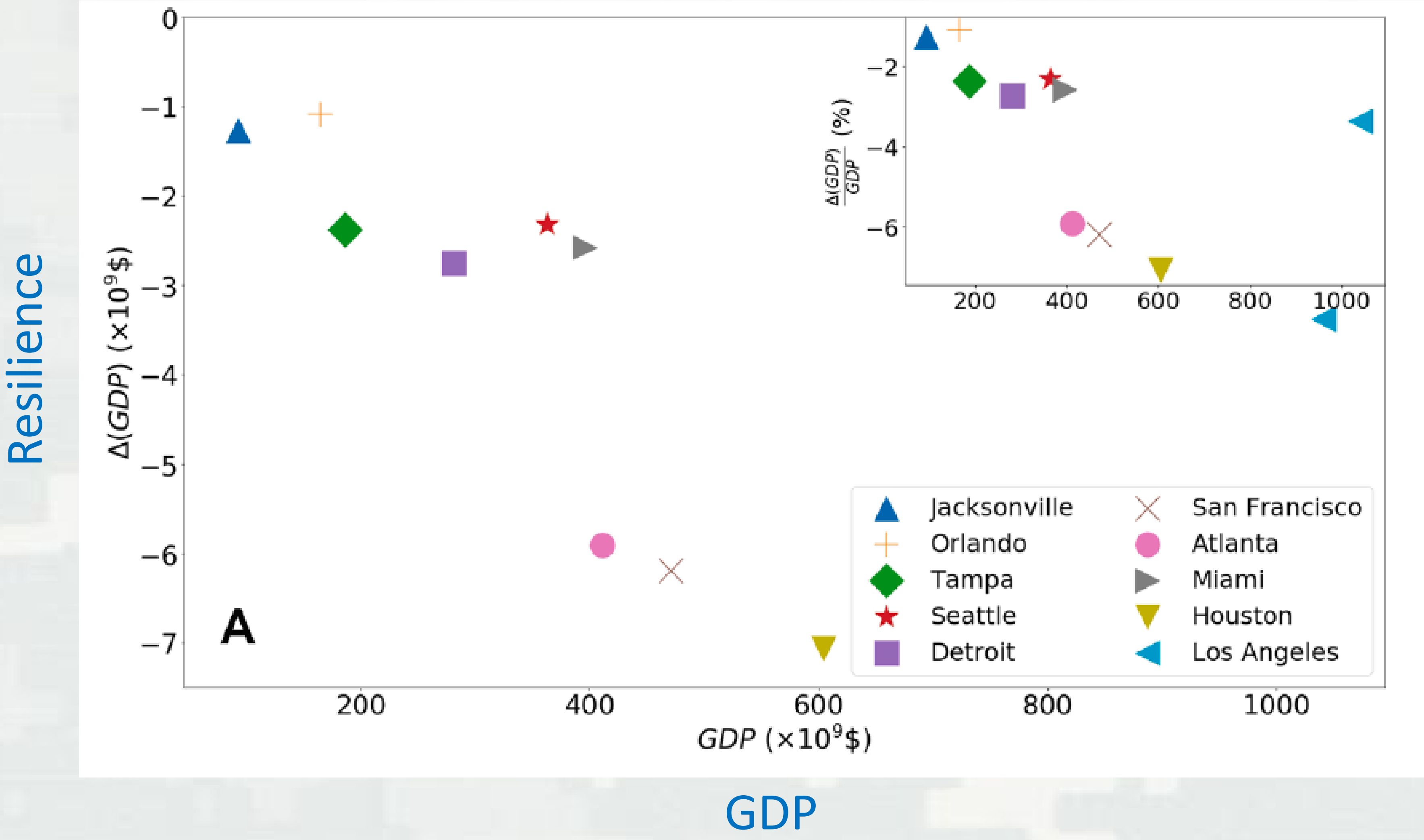
journal homepage: www.elsevier.com/locate/trd

Lack of resilience in transportation networks: Economic implications

Impact on GDP



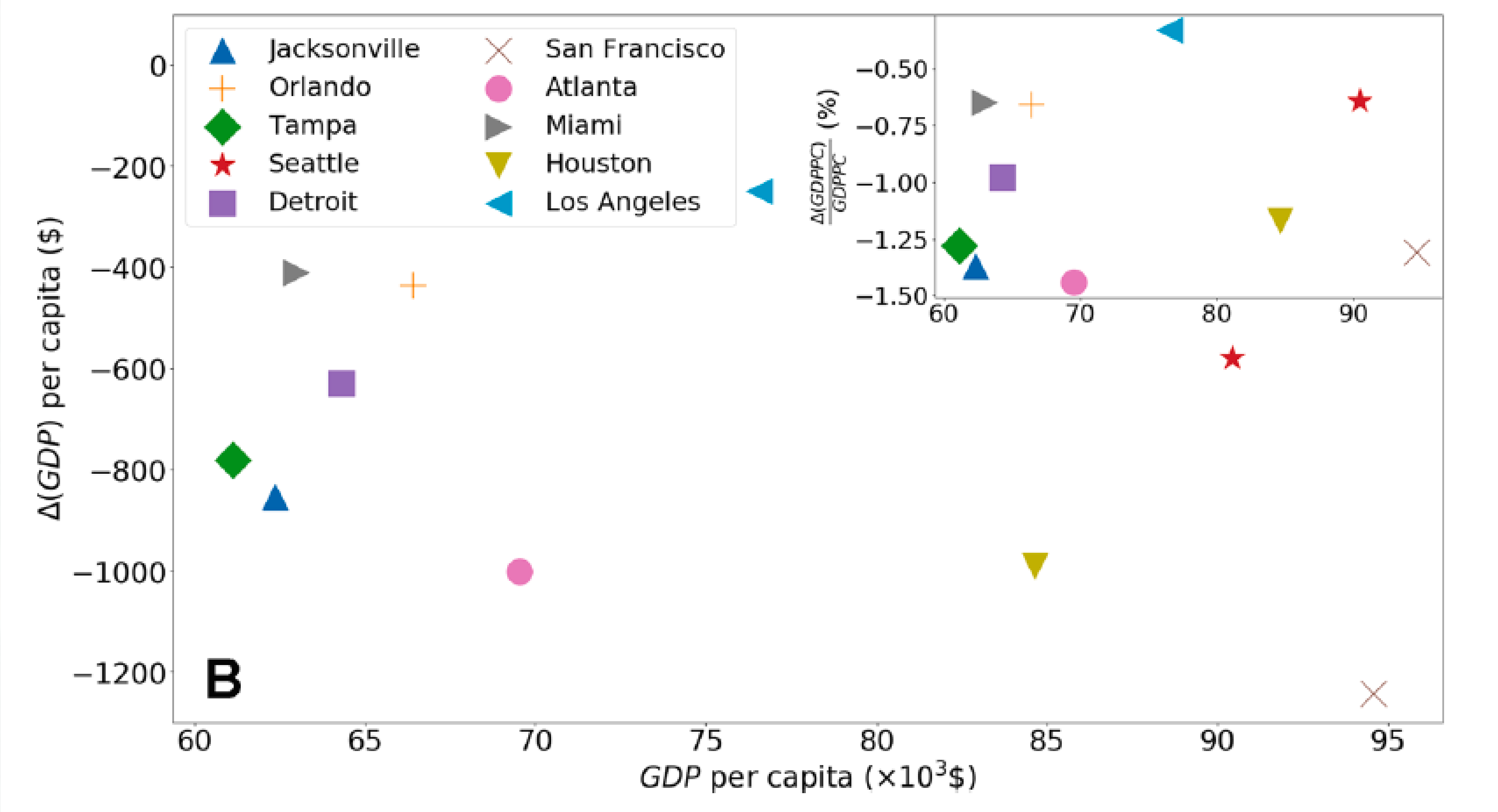
Resilience in Big Cities



After Kurth et al., 2020

Resilience in "Rich" Cities

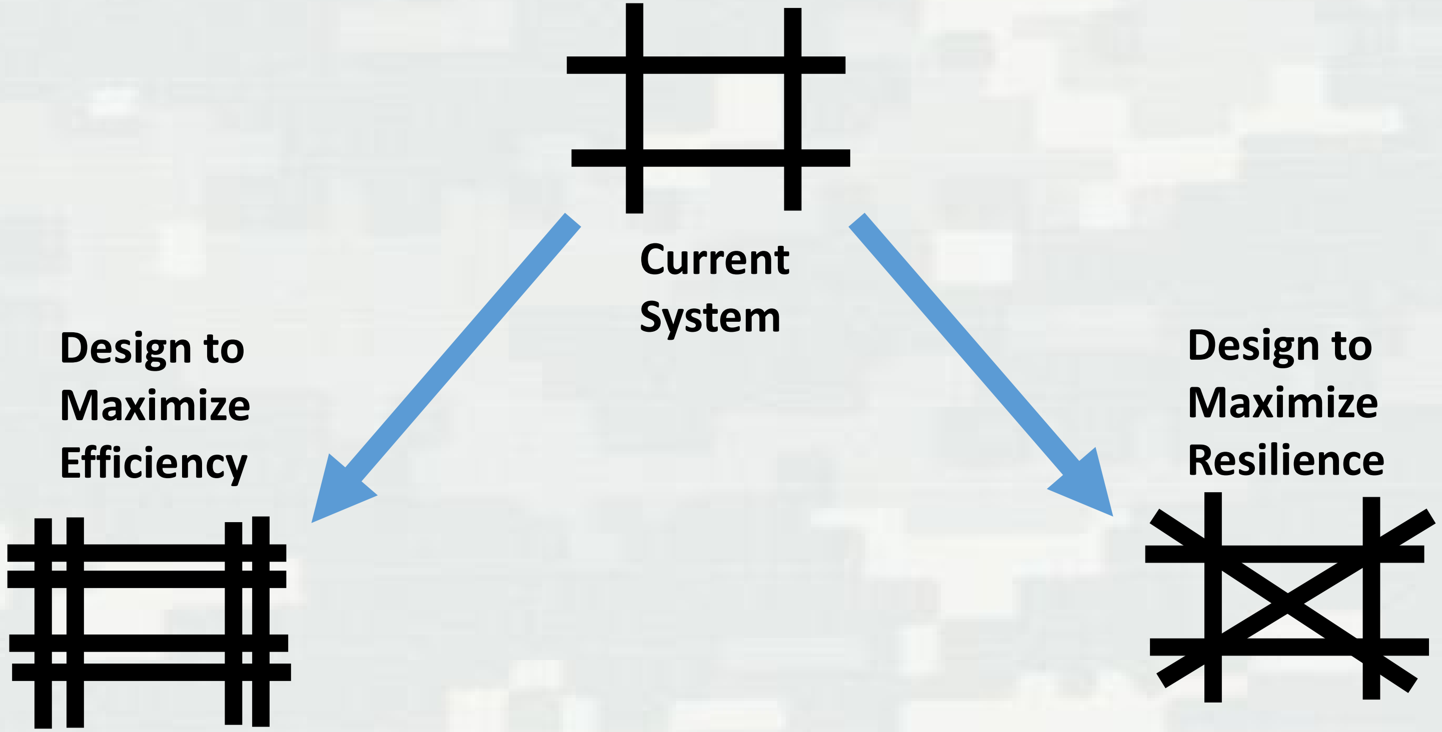
Resilience



GDP Per Capita

After Kurth et al., 2020

Managing Resilience is Different than Efficiency



Efficiency

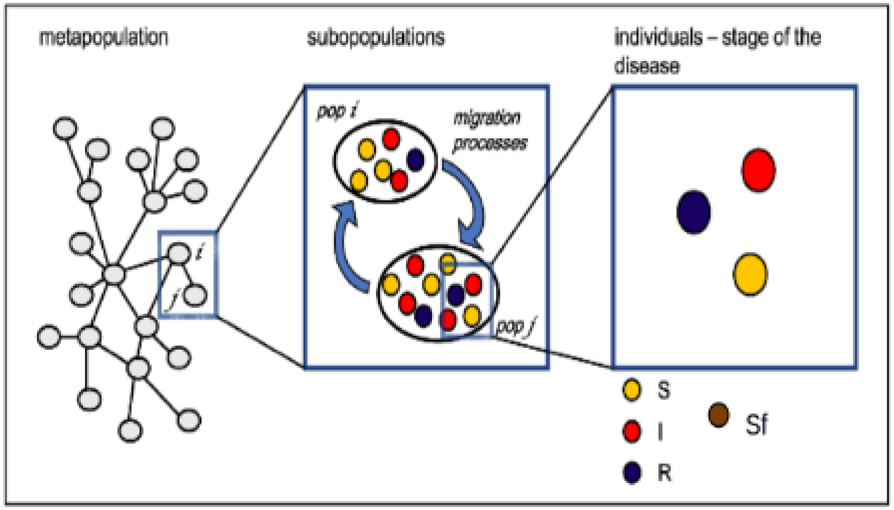
- the ability to move quickly when the network is functioning as designed
- cost effectively improved by increasing capacity on existing and highly utilized right of ways

Resilience

- the ability to limit delays from network component failures
- best improved by provide alternative route capacity when failure does occur

Resilience and Epidemic Spread

The resilience is defined as a competition process between commuters and disease spreading in a metapopulation system.



After Massaro et al., 2018

Three Behavioral Disease models

1. Local Information

2. Global Information

3. Local, belief-based spread of the fear of the disease

SCIENTIFIC REPORTS

OPEN

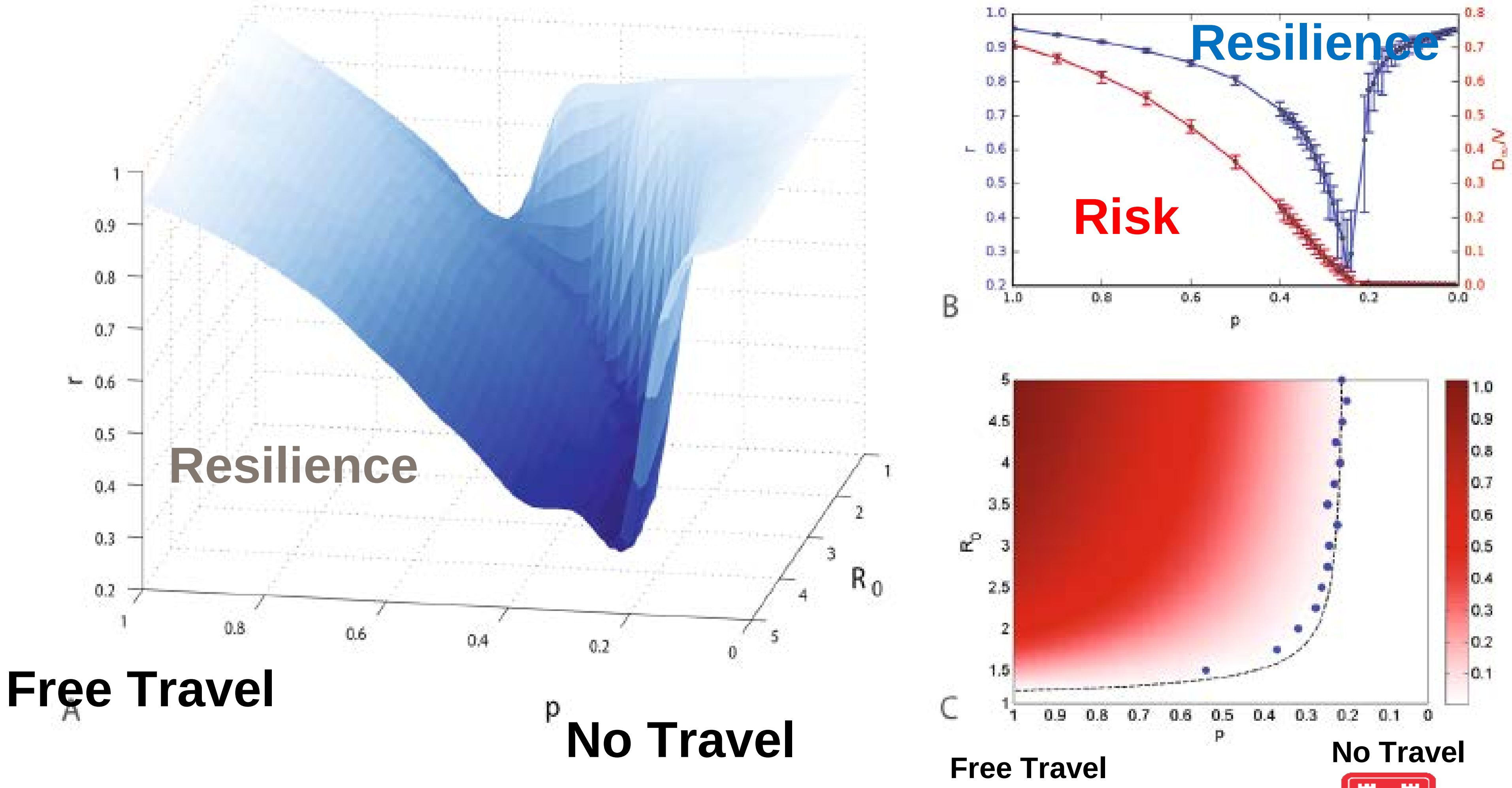
Resilience management during large-scale epidemic outbreaks

Emanuele Massaro[1,2,3], Alexander Ganin[1,4], Nicola Perra[5,6,7], Igor Linkov[1] & Alessandro Vespignani[6,7,8]

Received: 26 September 2017
Accepted: 5 January 2018
Published online: 30 January 2018

Assessing and managing the impact of large-scale epidemics considering only the individual risk and severity of the disease is exceedingly difficult and could be extremely expensive. Economic consequences, infrastructure and service disruption, as well as the recovery speed, are just a few of the

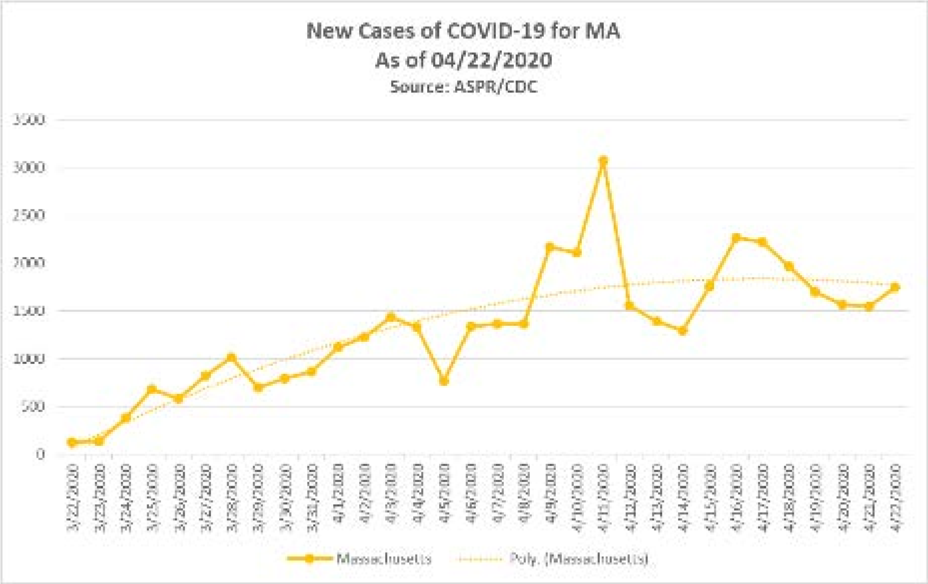
Resilience, Risk and Travel Restrictions



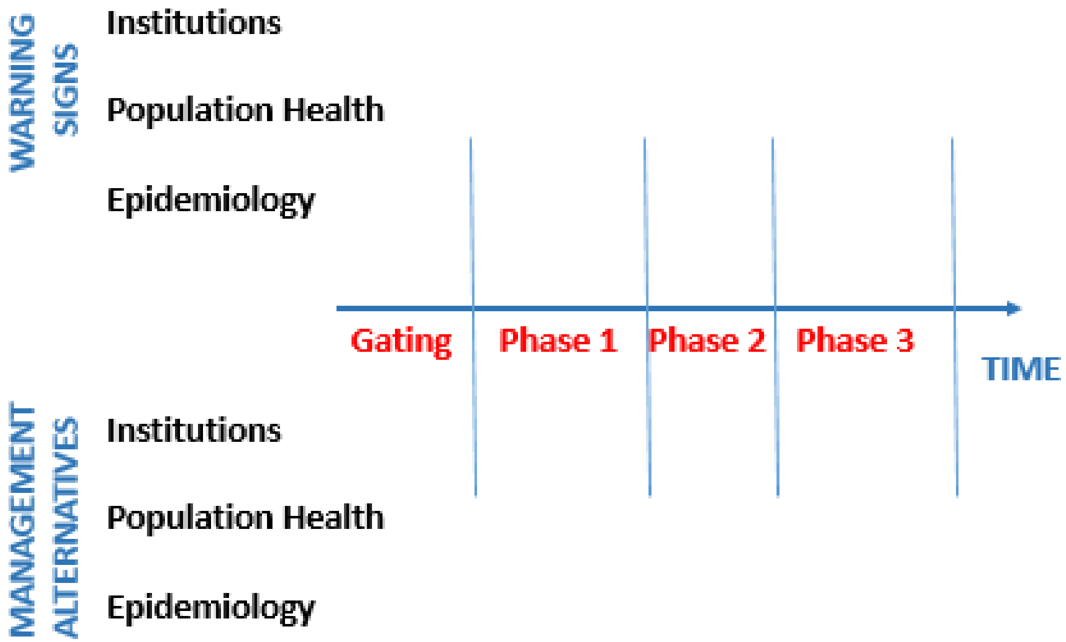
From Massaro, Linkov et al (2018)

Supporting FEMA Region 1:

Translate State-specific COVID-19 and socio-political realities into an actionable plan consistent with federal guidelines.

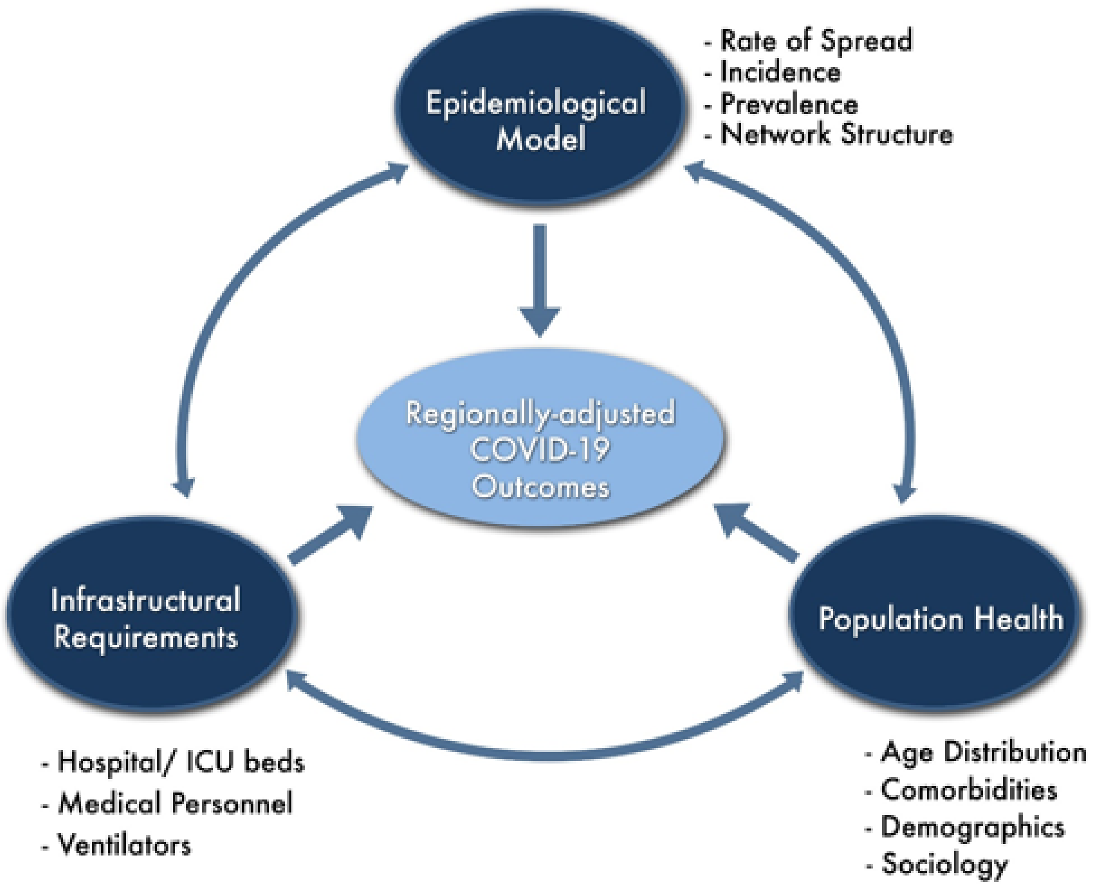


- There will be future public health challenges related to secondary waves
- Modeling and analytical tools should continue to be developed

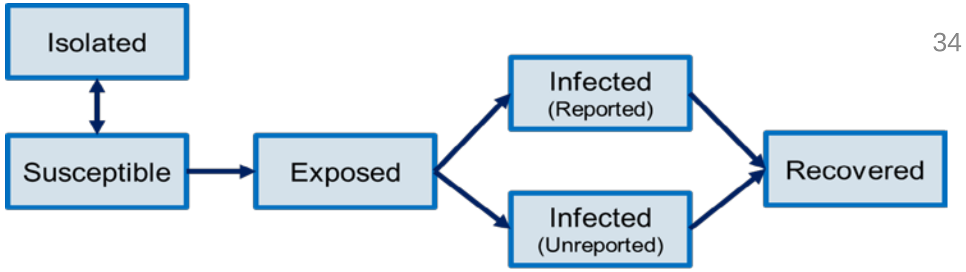


How Can This Be Achieved?

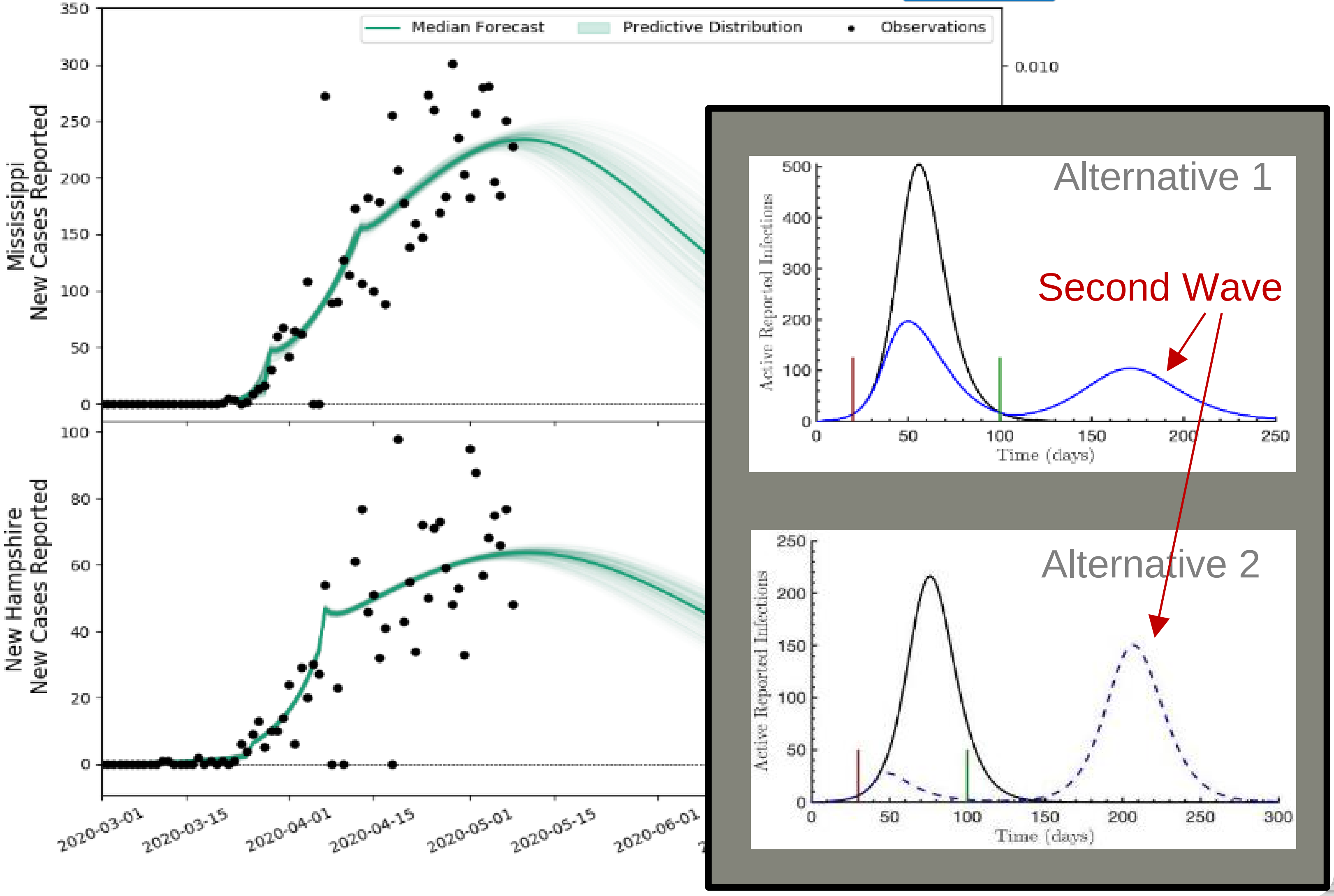
- Modeling Epidemics in New England
- New England Health and Institutional Requirements
- Modeling Recovery and 2nd Wave



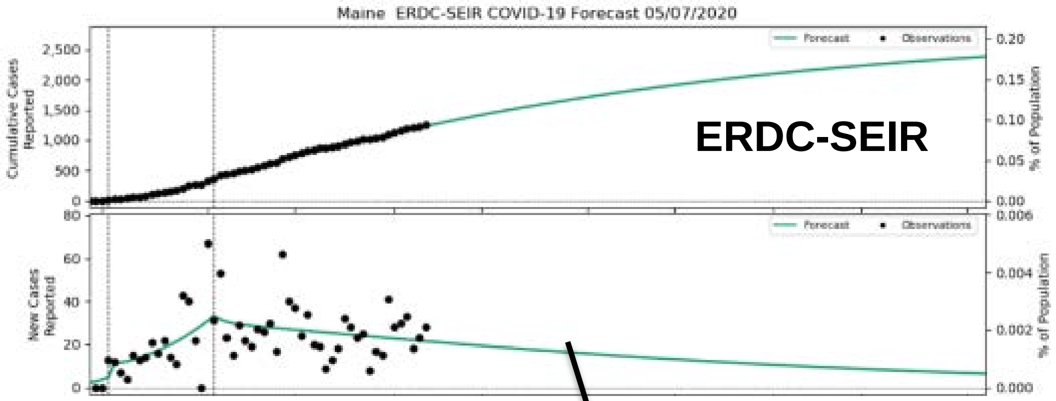
ERDC SEIR Model



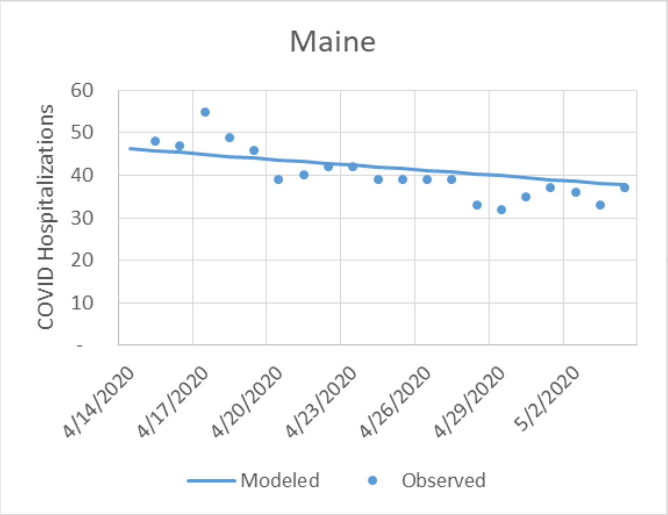
- Adapted SEIR approach - Splits Infected population into “reported and “unreported
- Dynamics statistically combined with observations and SME knowledge
- Parameters updated daily with new data
- Model parameters change with varying social distancing restrictions
- Prediction uncertainty from unconstrained parameters is characterized



FEMA R1-Tool:
Translating Model into Institutional Requirements



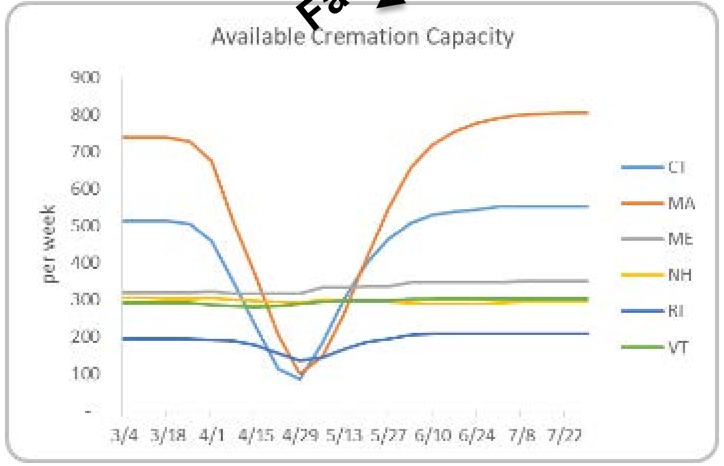
Hospitalizations



Beds

	Beds Needed for COVID Patients					
week	CT	MA	ME	NH	RI	VT
3/18/2020	72	155	17	12	10	10
3/25/2020	408	859	31	40	43	36
4/1/2020	804	1,658	49	73	96	59
4/8/2020	1,255	2,510	51	84	233	61
4/15/2020	1,562	3,296	47	98	446	50
4/22/2020	1,586	3,615	44	113	563	26
4/29/2020	1,453	3,606	41	129	558	10
5/6/2020	1,061	3,191	38	145	408	4
5/13/2020	657	2,403	35	161	213	2
5/20/2020	369	1,607	33	176	95	1
5/27/2020	196	994	30	189	40	0
6/3/2020	101	587	28	199	17	0
6/10/2020	51	337	25	206	7	0
6/17/2020	26	190	23	209	3	0

Fatality Management



PPE

	CONVENTIONAL BURN RATES					
	N95s or other respirators					
week	CT	MA	ME	NH	RI	VT
5/6/2020	146,576	471,367	6,025	22,265	53,767	469

	CONTINGENCY BURN RATES					
	N95s or other respirators					
week	CT	MA	ME	NH	RI	VT
5/6/2020	67,569	219,276	2,823	10,515	24,627	211

	CRISIS BURN RATES					
	N95s or other respirators					
week	CT	MA	ME	NH	RI	VT
5/6/2020	12,400	39,703	506	1,862	4,562	40

Moving Forward

Environment Systems and Decisions
https://doi.org/10.1007/s10669-020-09776-x

SHORT COMMUNICATION

Bouncing forward: a resilience approach to dealing with COVID-19 and future systemic shocks

William Hynes[1] · Benjamin Trump[1] · Patrick Love[1] · Igor Linkov[1]

1.) **Recovery and Building Resilience in the Local Economy**

Preserve and Recover from Disruptions to Local Economies

2.) **Household Resilience**

Bolster consumer/household resilience to shock

3.) **Company/Business Resilience**

Prevent Company Bankruptcies, Layoffs, and/or Shutdown While Complying With Pandemic Response Requirements.

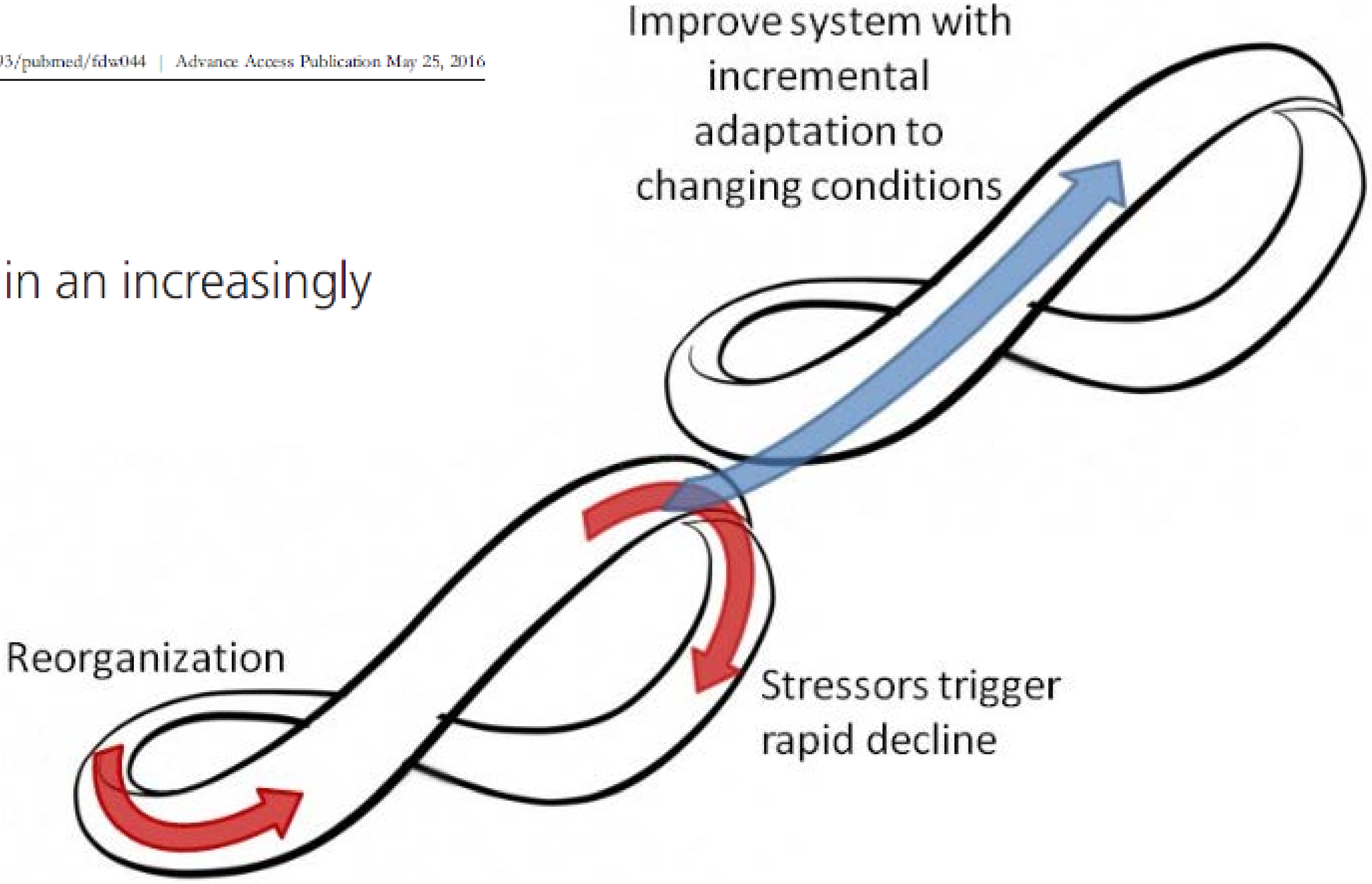
Civilizational Ups and Downs: Thinking in Systems and Resilience

Journal of Public Health | Vol. 39, No. 2, pp. 254–257 | doi:10.1093/pubmed/fdw044 | Advance Access Publication May 25, 2016

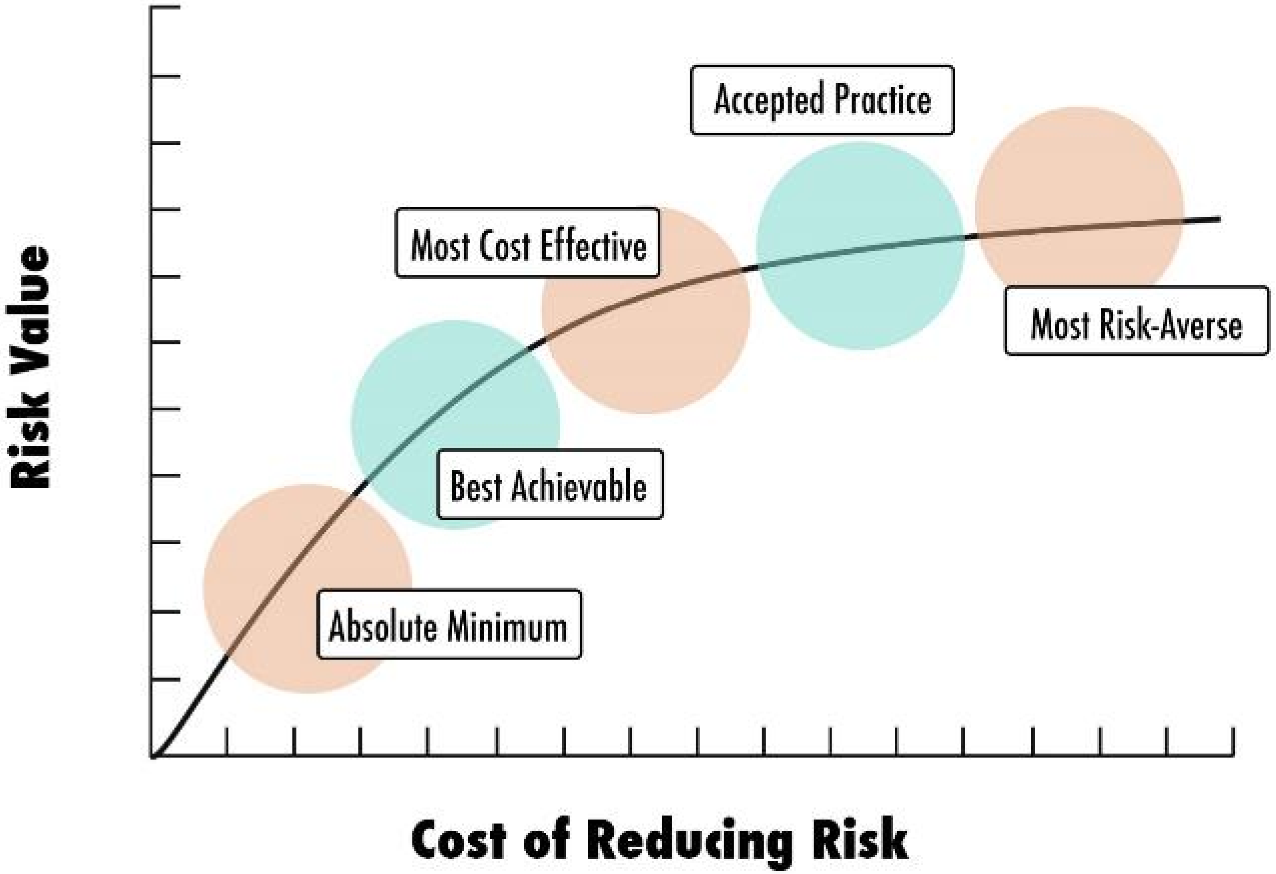
Perspectives

Disease epidemics: lessons for resilience in an increasingly connected world

S.N. DeWitte[1], M.H. Kurth[2], C.R. Allen[3], I. Linkov[2]



Why Resilience? Diminishing Returns of Risk-Based Approaches



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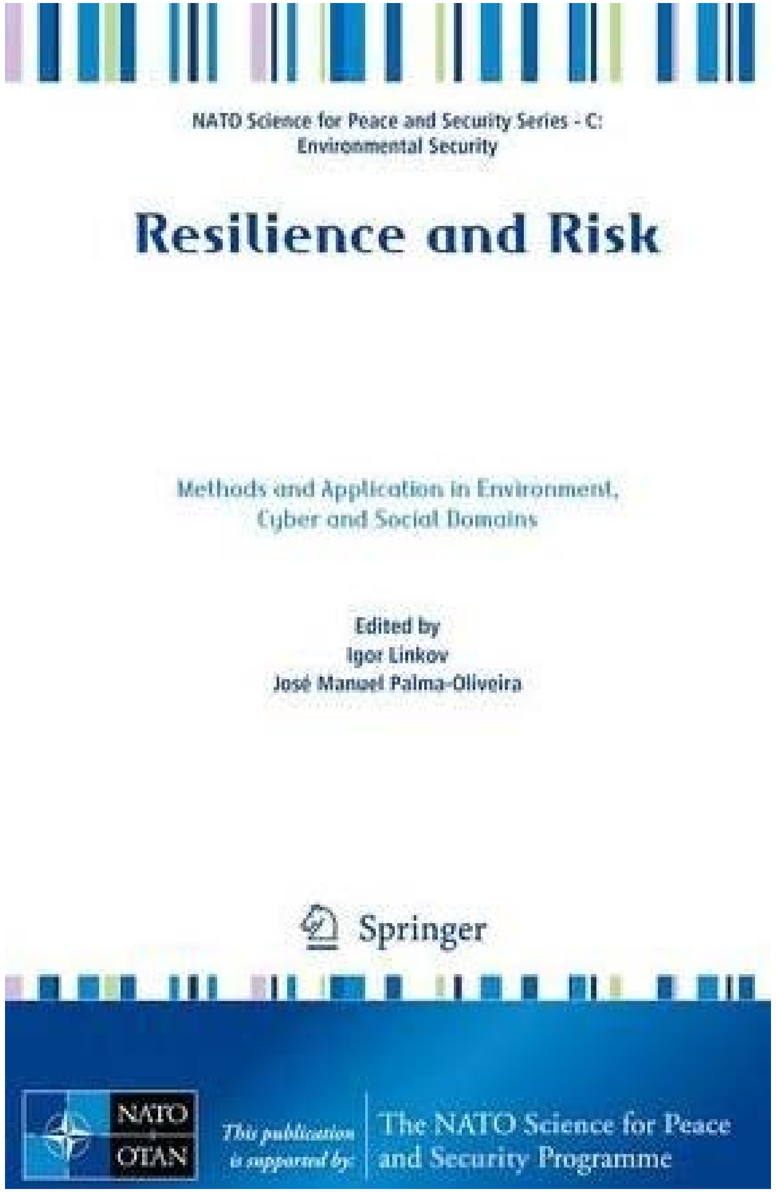

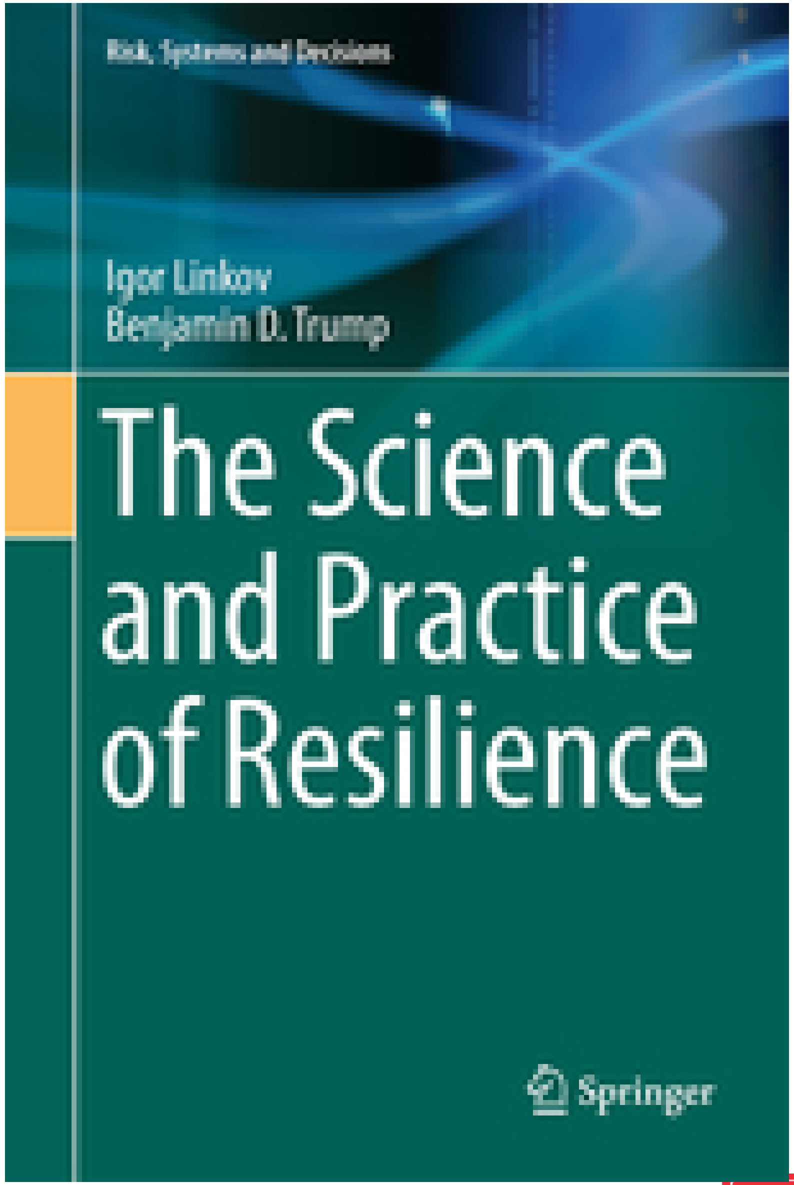

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